*Consulting Electrical and Mechanical Engineers: Messrs. Merz and McLellan*

APR 19 1961
TEXAS ENGINEERS LIBRARY
COLLEGE STATION, TEXAS

# and AEI

Six 100-MW generators for Stage One of the massive hydro-electric project at Kariba, on the Zambesi river, are being supplied by AEI. They are the largest hydro-electric generators in the entire continent of Africa.

**AEI**

**Associated Electrical Industries Limited**
**Heavy Plant Division**
RUGBY, ENGLAND

A5552

# *Research for Perfection*

*The Reyrolle Research Station used for the short-circuit proving and development-testing of their switchgear*

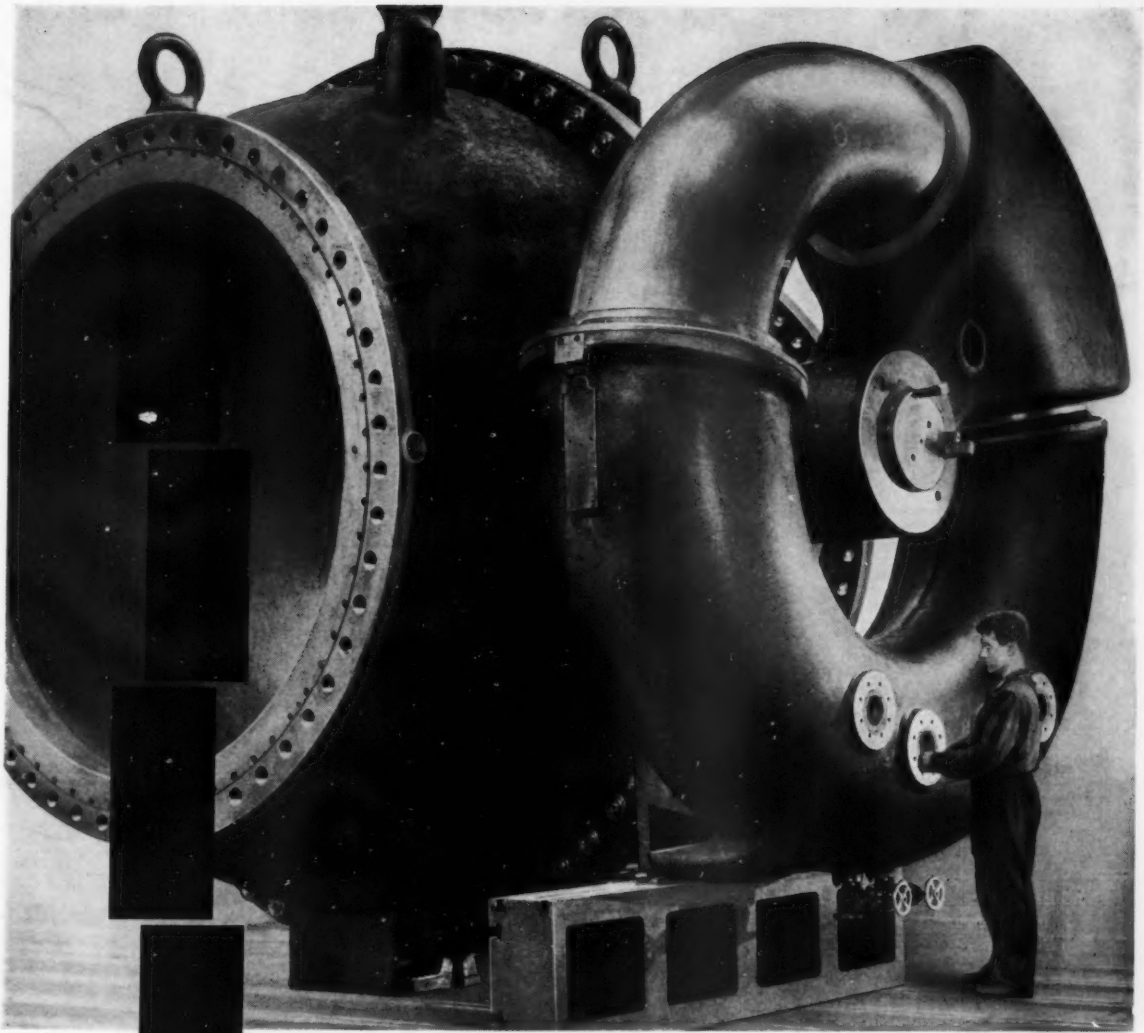
**All Reyrolle products are backed by highly organised research and development facilities to ensure the excellence of performance for which they are noted**

*Specialists in the manufacture of :*

AIR-BLAST SWITCHGEAR
SMALL-OIL-VOLUME SWITCHGEAR
METALCLAD SWITCHGEAR
AIR-BREAK SWITCHGEAR
FLAMEPROOF SWITCHGEAR
DISTRIBUTION SWITCHGEAR
CONTROL EQUIPMENT
PROTECTIVE GEAR
ARC-WELDING EQUIPMENT
A.C. COMMUTATOR MOTORS
ELECTRICAL ACCESSORIES

**Reyrolle**

**A. REYROLLE & CO. LTD - HEBBURN - COUNTY DURHAM - ENGLAND**



Assembly of a Spherical Valve
destined for
Le Marinel Power Station
(Congo)
nominal diameter 2200 mm (87 in.),
working pressure 18 kg/cm² (256 psi),
with patented
Ring-Piston Servomotor

This is the stone
that makes
the tower
stand or fall.
In a Power Station
it is the **Shut-off Valves**
that provide for the safety
of the entire plant
**and thereby**
**make it stand or fall**

323

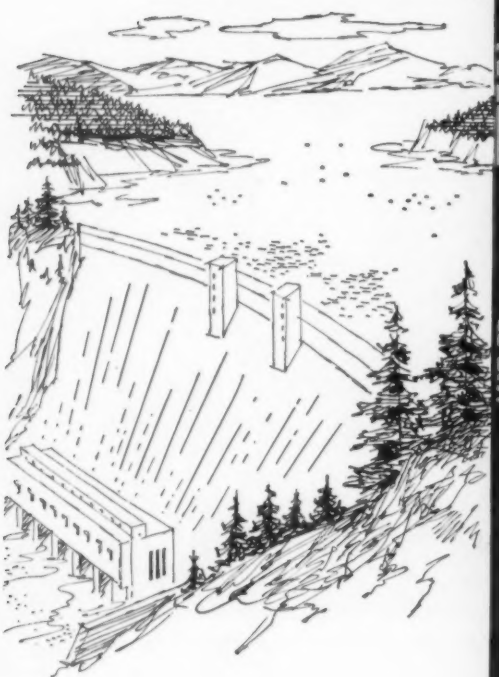
# DE ROLL

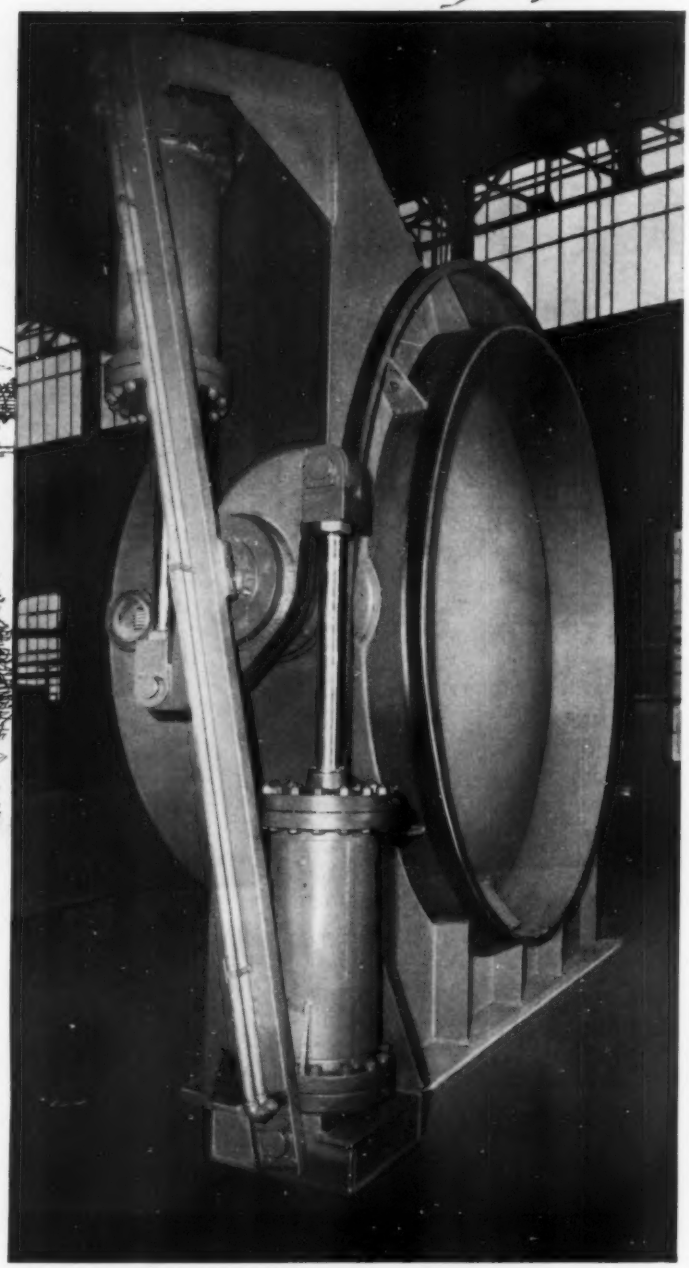
## Shut-off Valves

our speciality

DE ROLL Iron Works, Klus (Switzerland)

# Butterfly Valves





Designed for 80 p.s.i. water pressure and emergency closing against flow of 1,680 C.F.S. under 123 ft. head, the illustration shows a shop photo of one of three 12'-0" Turbine Shut-off Butterfly Valves built for a progressive mining Company in Quebec.

The valve body and disc are entirely fabricated from Steel Plate with the seal seat and disc seal of Stainless Steel. The seal of the disc is adjustable.

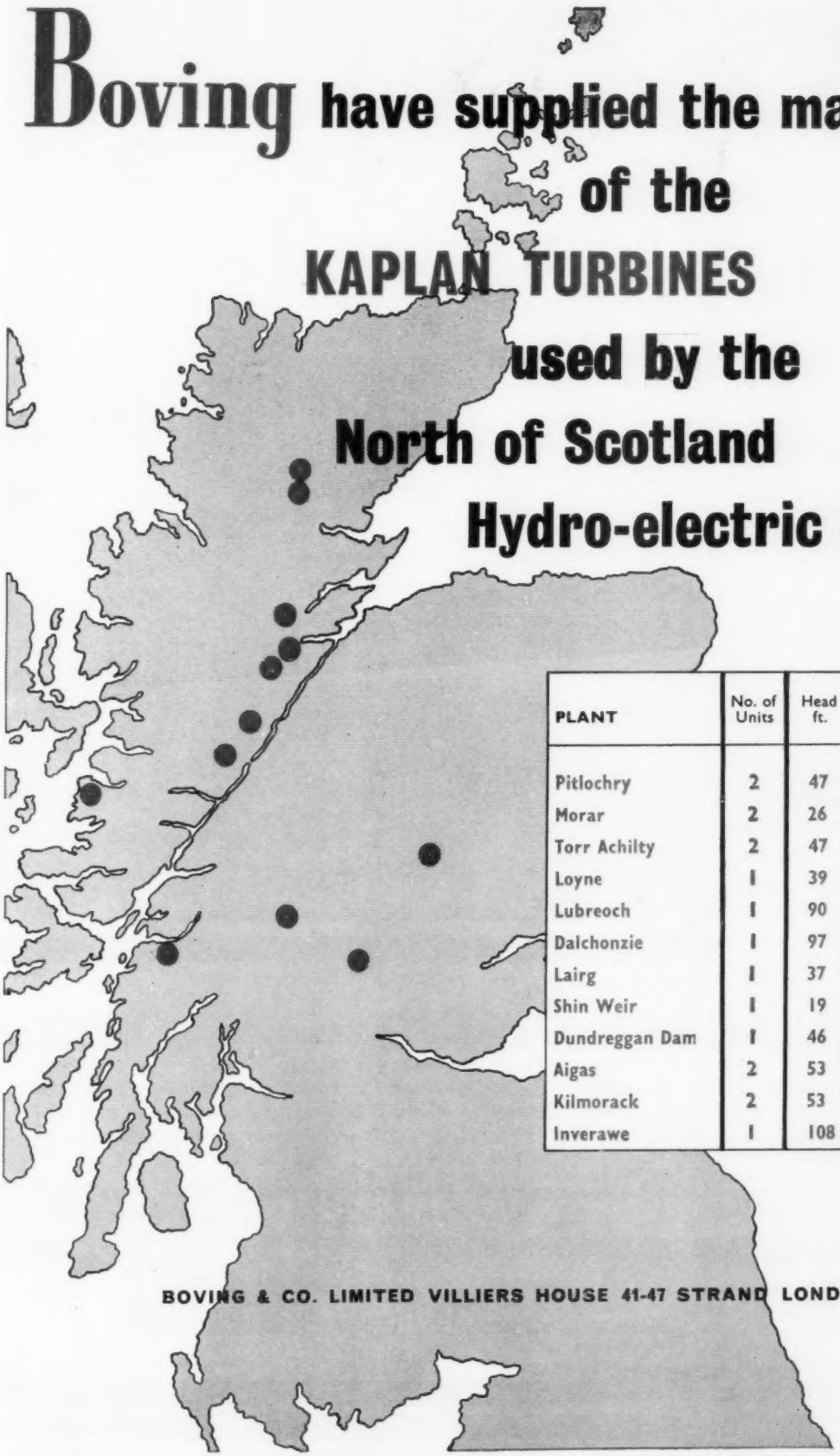
Another example of the fine engineering Industry expects from the shops of Canadian Vickers.

CANADIAN CJ VICKERS LIMITED

MONTREAL • TORONTO

MEMBER OF THE VICKERS GROUP

# Boving have supplied the majority of the KAPLAN TURBINES used by the North of Scotland Hydro-electric Board



| PLANT | No. of Units | Head ft. | Speed r.p.m. | Output per Unit B.H.P. |
|---|---|---|---|---|
| Pitlochry | 2 | 47 | 167 | 10,900 |
| Morar | 2 | 26 | 333 | 730 |
| Torr Achilty | 2 | 47 | 167 | 10,900 |
| Loyne | 1 | 39 | 434 | 735 |
| Lubreoch | 1 | 90 | 334 | 5,600 |
| Dalchonzie | 1 | 97 | 334 | 5,600 |
| Lairg | 1 | 37 | 167 | 4,900 |
| Shin Weir | 1 | 19 | 434 | 145 |
| Dundreggan Dam | 1 | 46 | 1020 | 225 |
| Aigas | 2 | 53 | 187 | 14,000 |
| Kilmorack | 2 | 53 | 187 | 14,000 |
| Inverawe | 1 | 108 | 167 | 42,500 |

BOVING & CO. LIMITED VILLIERS HOUSE 41-47 STRAND LONDON W.C.2.

# HITACHI

## Another Big Hydraulic Turbine and Generator by Hitachi

Hitachi has recently completed two 137,500 kW/125,000 kVA hydraulic turbines and generators for the Miboro Power Station in Central Japan. The turbine is of the vertical-shaft Francis type, and specified for a speed of 225 r.p.m., a maximum effective head of 200m and 76.6 cu.m/sec. water flow, making it one of the largest units of its kind in the world. Its runner has a maximum diameter of 3.7m and the main shaft a diameter of 95cm. The spiral casing, which was constructed in 13 sections to facilitate transportation to the site, has an inlet diameter of 3.35m and an outer diameter of 11.2m.

The generator presents a high-torsoed appearance, having been so designed in consideration of the comparatively high speed. Since the generator was designed for a rated voltage of 16,500 volts and. in this respect, represents the first such attempt in Japan, particular care was taken in the corona-shielding and impulse resistance of the stator winding. The generator is rated at 60 cycles, 225 r.p.m. and 0.9 power factor, but is also capable of operating at 50 cycles, 187.5 r.p.m. and 1.0 power factor.

Hitachi, Ltd.
Tokyo Japan
Cable Address: "HITACHY" TOKYO

64'000 HP Pelton Turbine Göschenen

**TRADITIONAL SWISS ENGINEERING SKILL AND QUALITY**

A century of experience in design and construction of waterpower-equipment and constant research in two hydraulic laboratories, one of them especially equipped for cavitation tests, assure the reliablity and efficiency for which Bell turbines are renowned

KRIENS Bell

**Bell builds:**
Water Turbines, Spherical straight flow valves, Butterfly valves, Penstocks and supply pipings, Pressure tunnel liners, Partially or fully automatic and remote controlled plants, Power house cranes, Towers for transmission lines, Water control equipment

**Some projects with Bell Equipment:**
**Francis Turbines** - Guyabo (El Salvador) head 56 m, 24'800 HP - Bärenburg (Switzerland) head 340 m, 85'000 HP (Supply together with Charmilles)
**Pelton Turbines** - Göschenen (Switzerland) head 698 m, 64'000 HP - Sedrun (Switzerland) head 588 m, 70'000 HP
**Kaplan Turbines** - Wildegg Brugg (Switzerland) head 15,3 m 34'000 HP - Petäjäskoski (Finnland) head 19 m, 67'600 HP

**Bell Engineering Works Ltd.**
**Kriens/Lucerne (Switzerland)**

# BUILDING FOR POWER

Huwood Conveyors are in wide use, not only in Britain but throughout the world—one of their most important applications being in the work of dam building for hydro-electric schemes.

They have been chosen because they offer the highest degree of adaptability to varying sites, the utmost reliability, and the minimum of routine maintenance.

# Huwood Conveyors

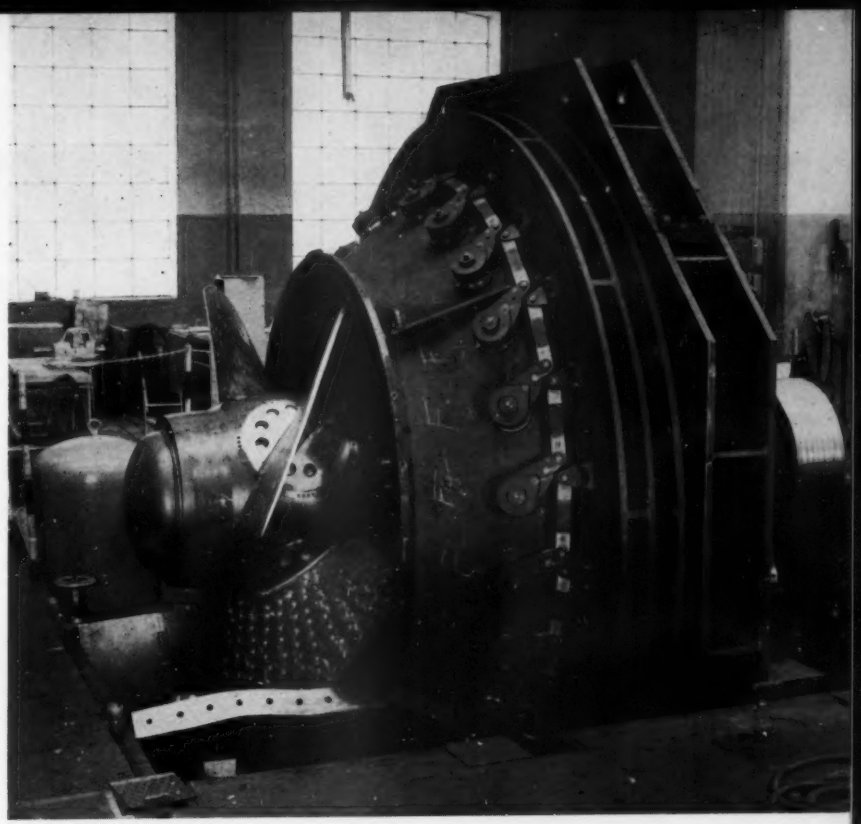
**HUGH WOOD & CO. LTD.**

*Head Office and Factories*
GATESHEAD-ON-TYNE, 11
Telegrams: Huwood, Gateshead. Telephone: Low Fell 76081 (5 lines).

*Industrial and Export Office*
ROYAL LONDON HOUSE, FINSBURY SQUARE, LONDON, E.C.2.
Telegrams: Huwood Stock, London. Telephone: Monarch 3273 (4 lines).

# Sweden's first tubular turbine

## now in service at Skogsforsen power station (Yngeredsfors Kraft AB)



KMW and ASEA have now completed the first tubular turbine unit in Sweden. The unit comprises in principle a horizontal Kaplan turbine with a direct-coupled synchronous alternator. The alternator is arranged concentrically in the waterway, so that the stator casing forms an extension of the internal wetted perimeter of the turbine. This setting provides a straight waterway with essentially axial flow.
Turbine output 4.875 h.p. at 14 m (46') net head and 250 r.p.m.

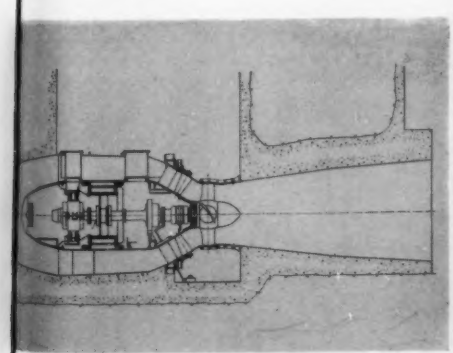
**Advantages :**

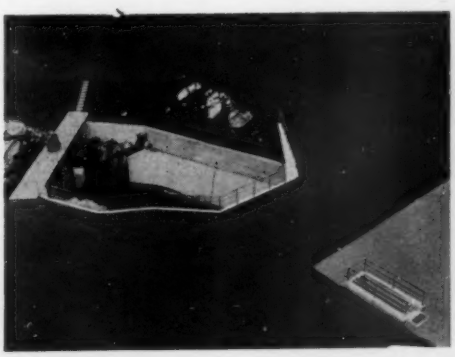
Simple design which permits wide variations.

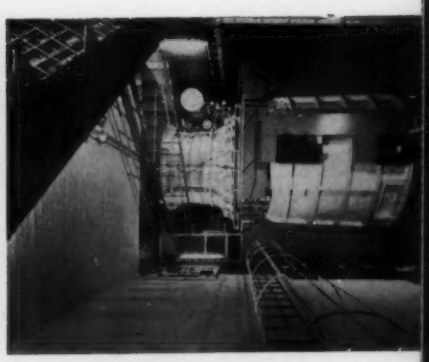
Small building requirements; the station building can be discreetly blended into the surrounding countryside.

Higher efficiency and shorter erection time than for a conventional turbine.

Permits the exploitation of power resources which had previously been regarded as uneconomical to develop.







**AB KARLSTADS MEKANISKA WERKSTAD**
**KARLSTAD · SWEDEN**

**KMW**

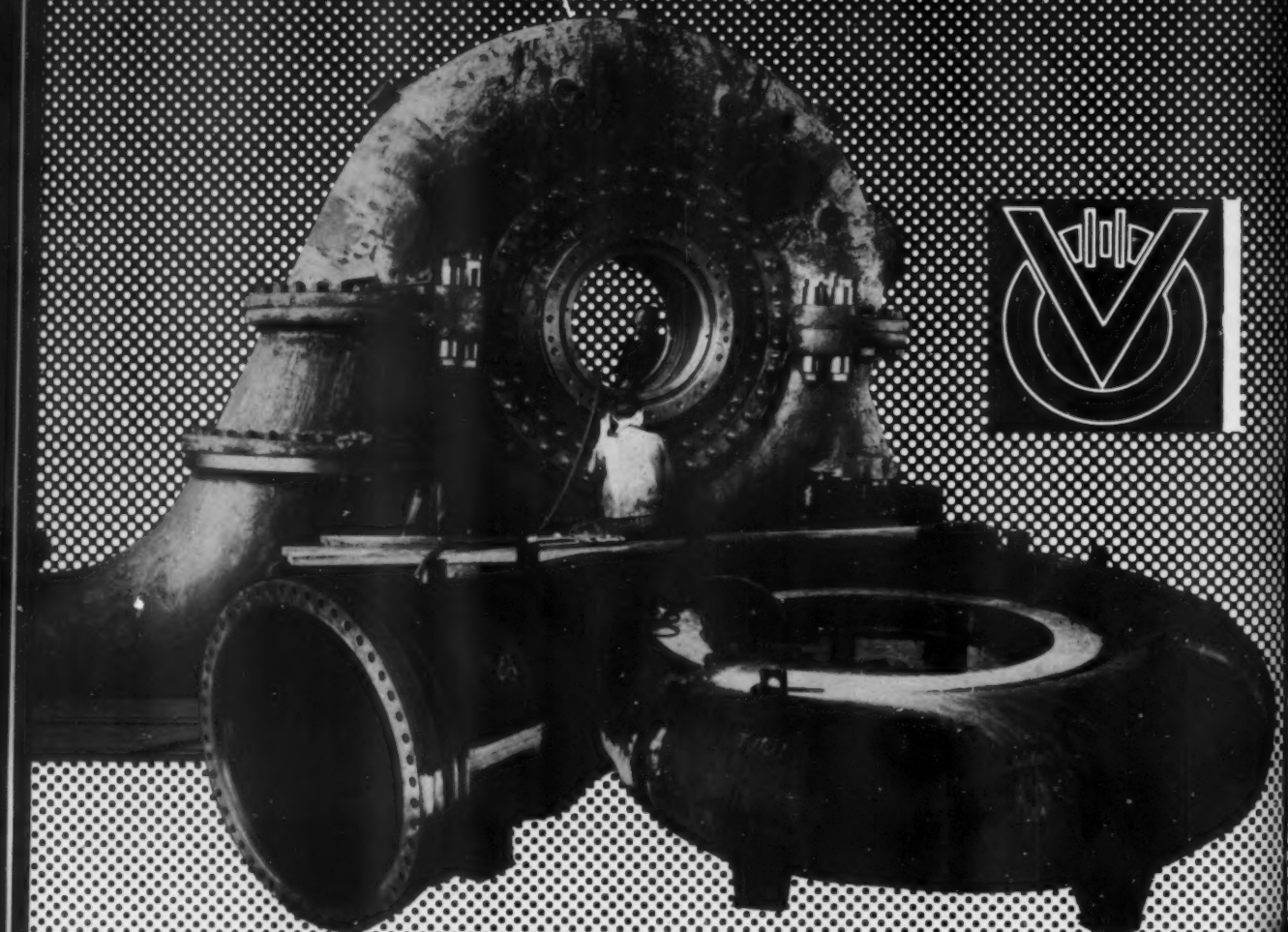
Representatives in Canada:

A. JOHNSON & CO. (Canada) LTD., P.O. BOX 56, MONTREAL 16

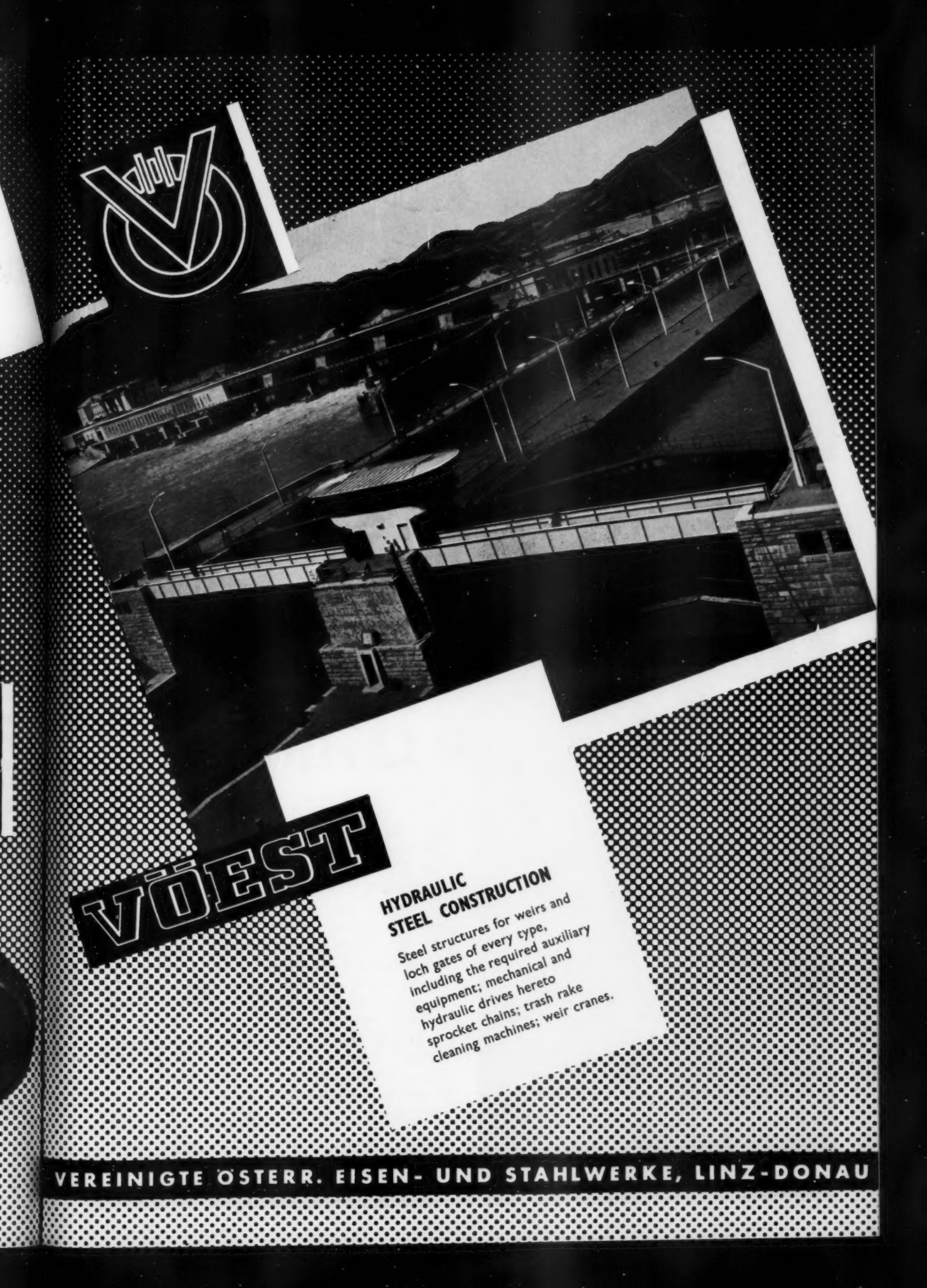
VÖEST

# Hydraulic Turbines, Spherical and Butterfly Valves

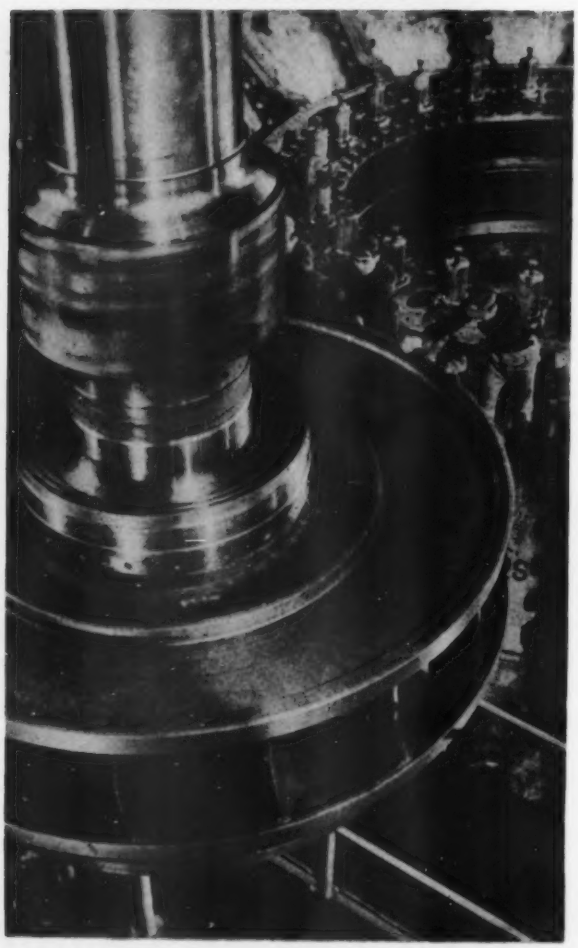
Licensed by Baldwin-Lima-Hamilton Corp.
Philadelphia, U.S.A.



VE


VÖEST
HYDRAULIC
STEEL CONSTRUCTION
Steel structures for weirs and
loch gates of every type,
including the required auxiliary
equipment; mechanical and
hydraulic drives hereto
sprocket chains; trash rake
cleaning machines; weir cranes.
VEREINIGTE ÖSTERR. EISEN- UND STAHLWERKE, LINZ-DONAU

Toshiba



# Contributing to Your Better Living!

Heavy electric equipment such as Water Turbines, Generators, Power Transformers, and testing equipment for Power Stations, are being shipped out one after another from Toshiba's Tsurumi works.

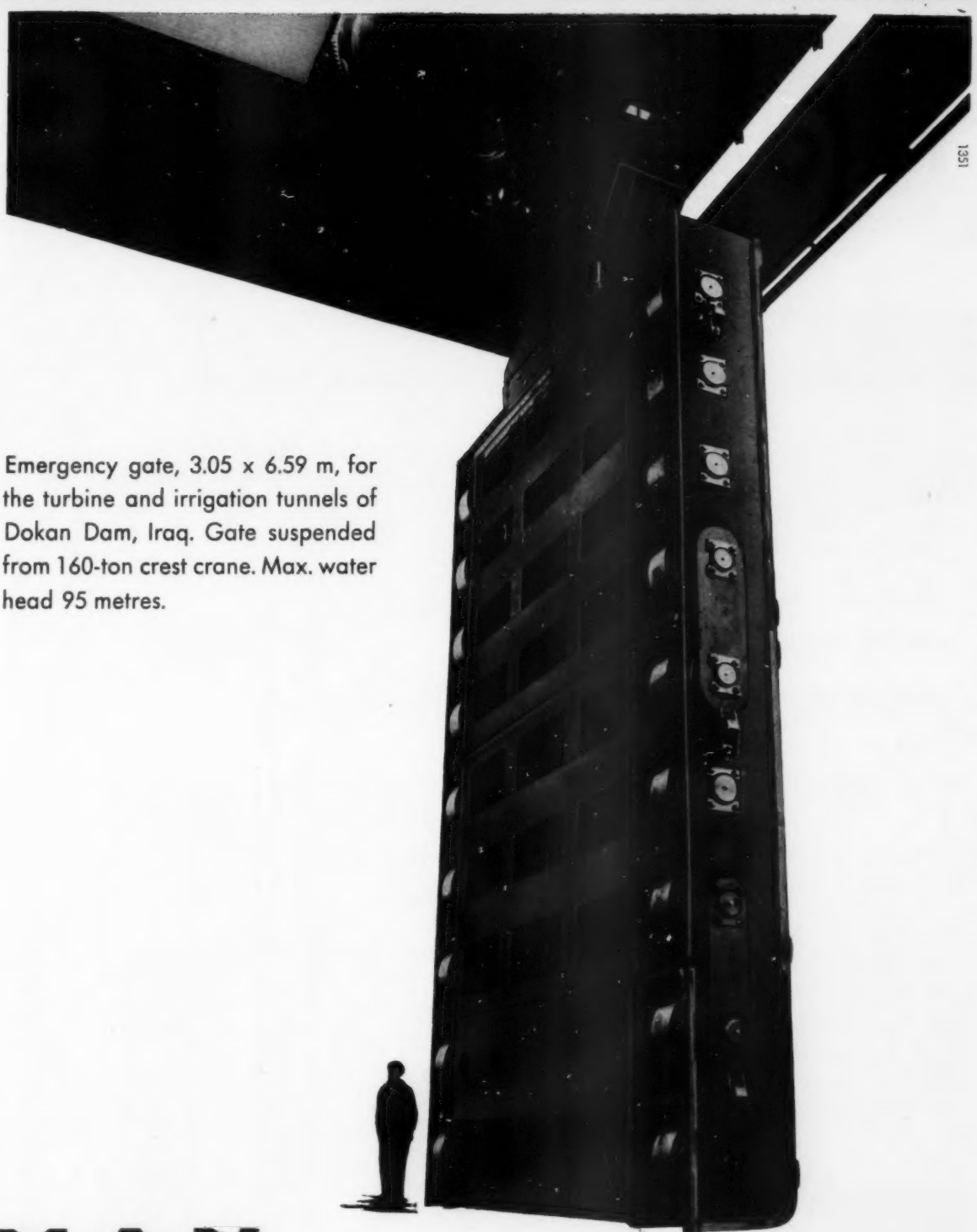
Shown above is one of the 3 scheduled 133,000 kVA generators—among the largest in the world—to be installed at Okutadami Power Station in central Japan.

The 137,000 KW Francis turbine, seen at left, to be coupled with this generator is also a Toshiba product. The runner diameter of this turbine is 4,000 mm, and ranks among the biggest in the world.

Similar generators with 58,000 kVA power has been installed at Mazatepec Power Station in Mexico and is now in full operation, Toshiba is also in production for various heavy equipment for many other new projects around the world.

Tokyo Shibaura Electric Co., Ltd.

2 Ginza Nishi 5-Chome, Chuo-ku, Tokyo, Japan
Cable Address: TOSHIBA TOKYO



1351

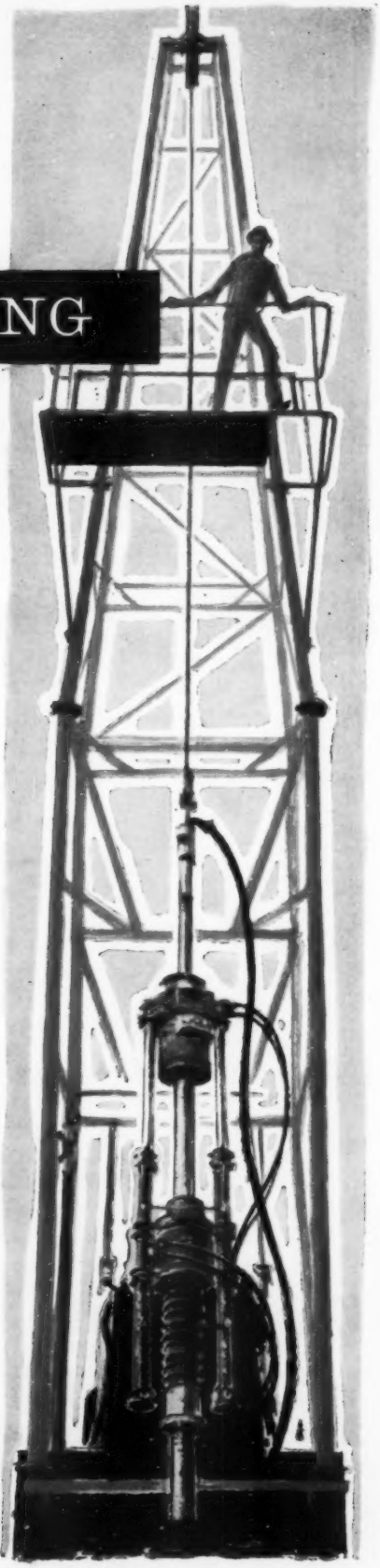
Emergency gate, 3.05 x 6.59 m, for the turbine and irrigation tunnels of Dokan Dam, Iraq. Gate suspended from 160-ton crest crane. Max. water head 95 metres.

# M·A·N
# HYDRAULIC STRUCTURES

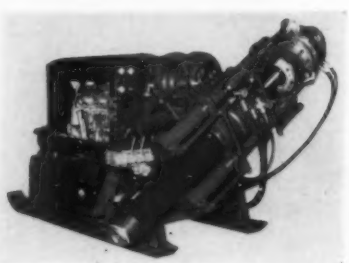
**MASCHINENFABRIK AUGSBURG-NÜRNBERG AG GUSTAVSBURG WORKS**
**GUSTAVSBURG/HESSEN (GERMANY) REPRESENTATIVES IN ALL COUNTRIES**

# DIAMOND DRILLING

We are at your service with skilled drillers, and equipment to undertake your drilling programme. Or alternatively to supply British manufactured machines and equipment for air or water flush drilling.



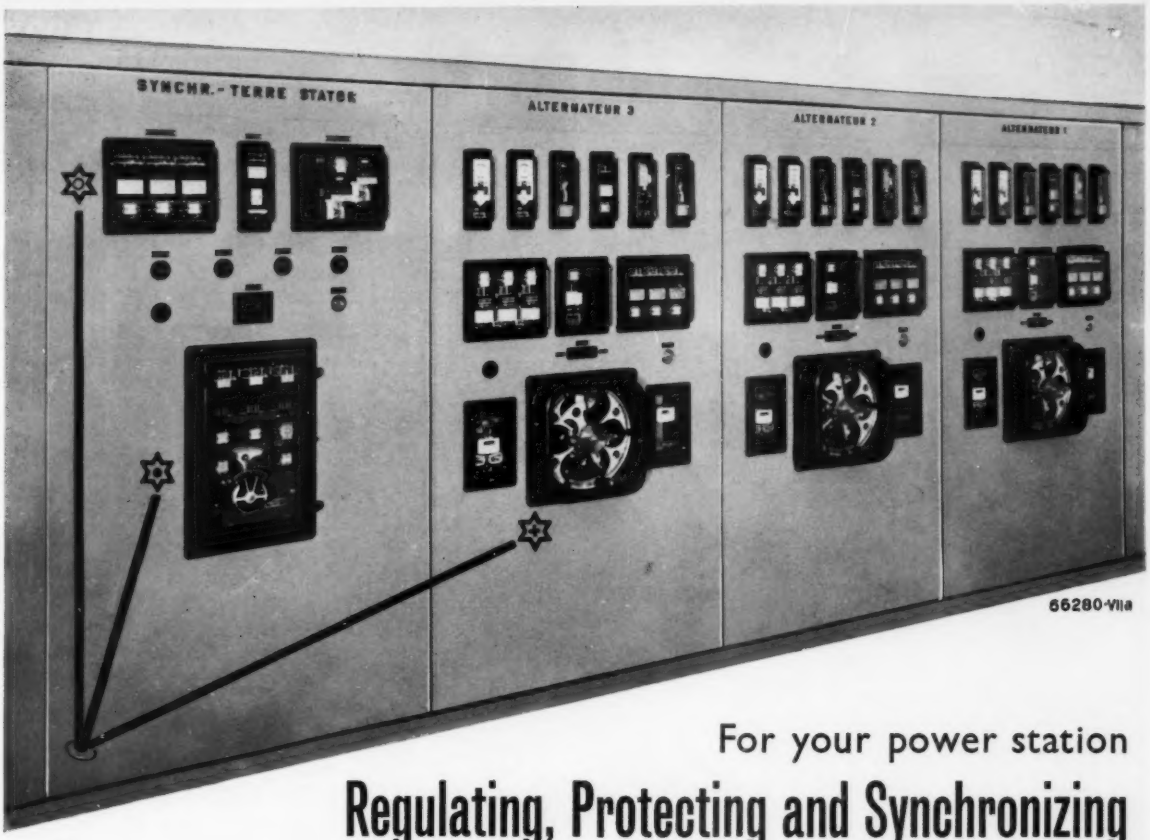
*Drills, derricks, pumps and equipment. Portable and flexible over a wide range of bore hole depths and sizes.*



**BOYLES BROS. DRILLING CO. LTD.**

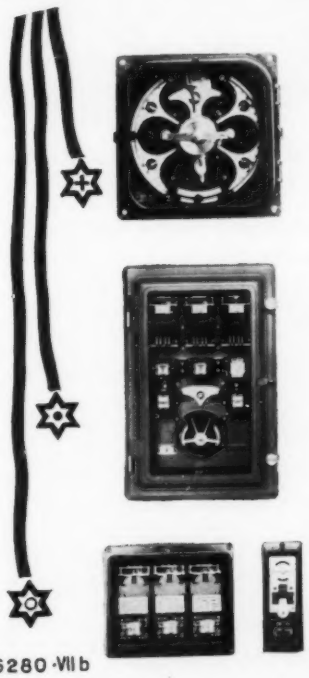
*Newcastle-upon-Tyne 3 · Phone: Newcastle 53901*

ASSOCIATED WITH BOYLES BROS. DRILLING CO. LTD., VANCOUVER, CANADA




For your power station

# Regulating, Protecting and Synchronizing Equipment!




**Quick-acting regulators**
A suitable model for every size of machine and every regulating duty. Accurate and robust.

**Automatic synchronizers**
for generating stations and substations; require little space, no maintenance, no adjustment; low power consumption. Rapid and reliable.

**Generator protecting gear**
comprising proved apparatus protect old and new machines. Adaptable and dependable.

Over 90,000 Brown Boveri quick-acting regulators have been installed since 1909.

Machines with an aggregate rating of millions of kVA are synchronized and protected by Brown Boveri equipment.

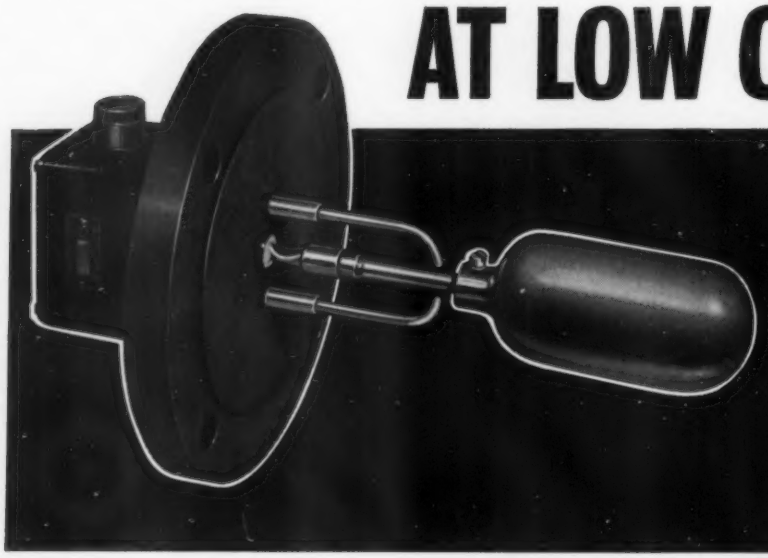
Our long experience may be of service to you.

BROWN BOVERI

**BROWN, BOVERI & CO., LTD.**
BADEN · SWITZERLAND

AEI INSTRUMENTATION INFORMATION SERVICE

# RELIABLE HIGH OR LOW LEVEL INDICATION AT LOW COST



AEI

LIQUID LEVEL ALARM SWITCH MODEL 26

This simple and robust unit is operated by the change in the buoyancy of a displacer—transmitted to a micro-switch by means of a rigid tongue with in a patented flexible shaft. Only a small movement—approximately $\frac{1}{32}$" and equivalent to a level change of about $\frac{1}{2}$" at a specific gravity of 1.0—is required to actuate the switch. There are no pivots to clog or go wrong, no magnets which can lose their strength.

The low cost and dependability of the Model 26 alarm switch make it a practical and economical proposition for boilers, vessels and tanks of all sizes where reliable indication of high or low level is necessary.

- **Patented flexible shaft—no pivots or rubbing parts**
- **Standard flange fitting—to install**
- **Limit stops protect flexible shaft**
- **Direct or reverse acting**

Mail this coupon for full details

Associated Electrical Industries Limited Instrumentation Division, P.O. Box 1, Harlow, Essex.

NAME .....

POSITION .....

COMPANY ADDRESS .....

.....

AEI

**Instrumentation Division · Process Control Dept.:**
**Associated Electrical Industries Limited**
P.O. Box 1 · Harlow · Essex Tel: Harlow 25221

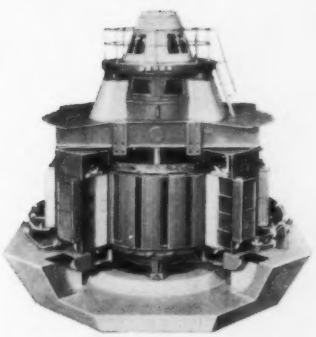
sc/111

*The Australian Prime Minister, the Rt. Hon. R. G. Menzies and Sir William Hudson, Commissioner for Snowy Mountains Hydro-Electric Authority, inaugurating the Tumut 1 Power-station.*
(Photo: Snowy Mountains H. E. Authority)

# 640000 kVA

The Snowy Mountains Hydro-Electric Authority, Australia, has commissioned the first of two new power-stations, which together have a total output of 640,000 kVA. In the face of severe competition from leading electrical engineering firms from all over the world, ASEA was awarded the contract for all eight generators for these two power-stations.

*Further generators having a total output of 127,000 kVA are also being manufactured at present by ASEA for Australia.*

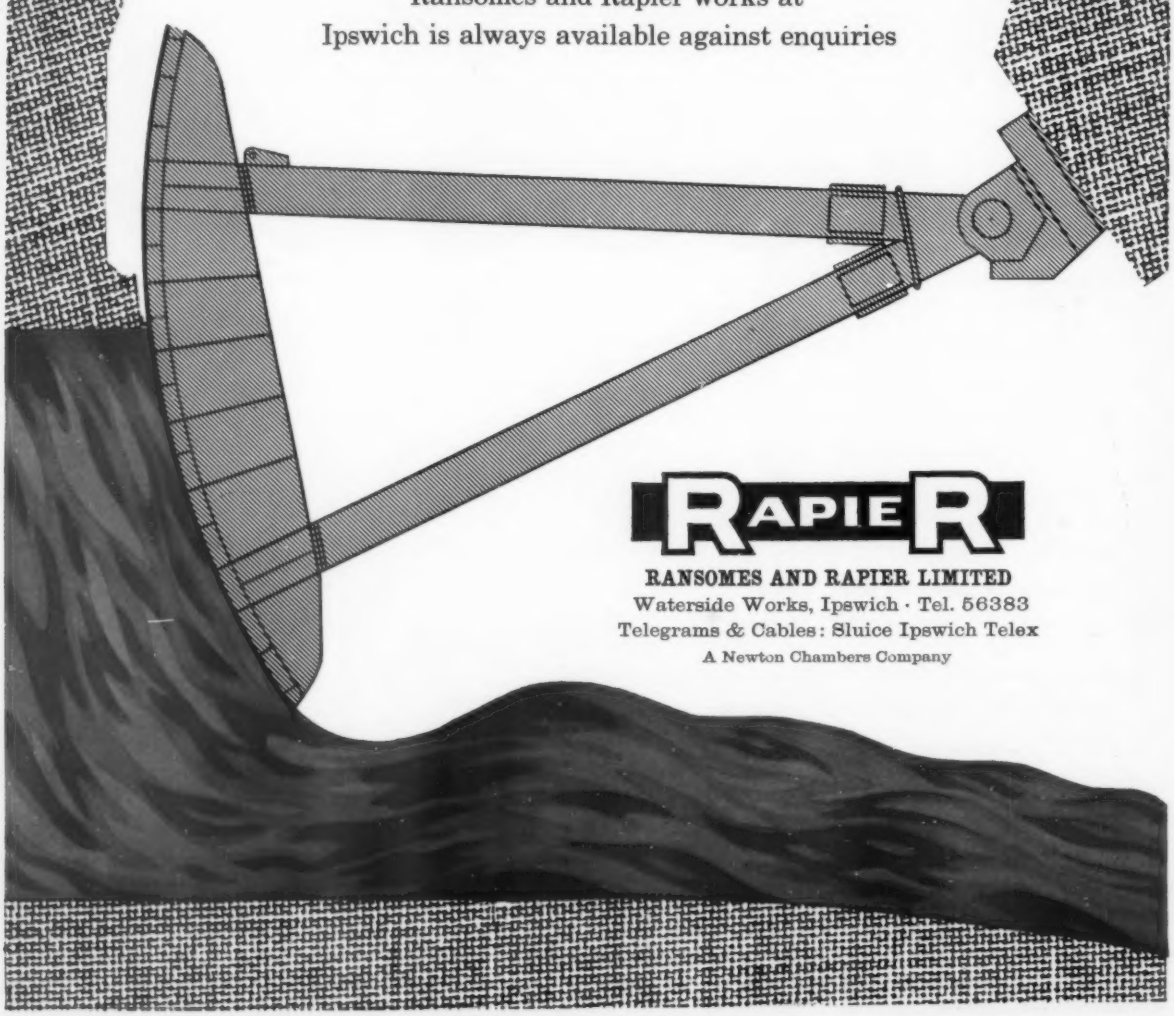


The largest power-station in Sweden, Stornorrfors, has an output of 450,000 kVA and supplies about 7 per cent of the total amount of electricity produced in the country. This power-station too is equipped with ASEA generators, and practically all electricity in Sweden is generated by ASEA machines.

ASEA
VÄSTERÅS

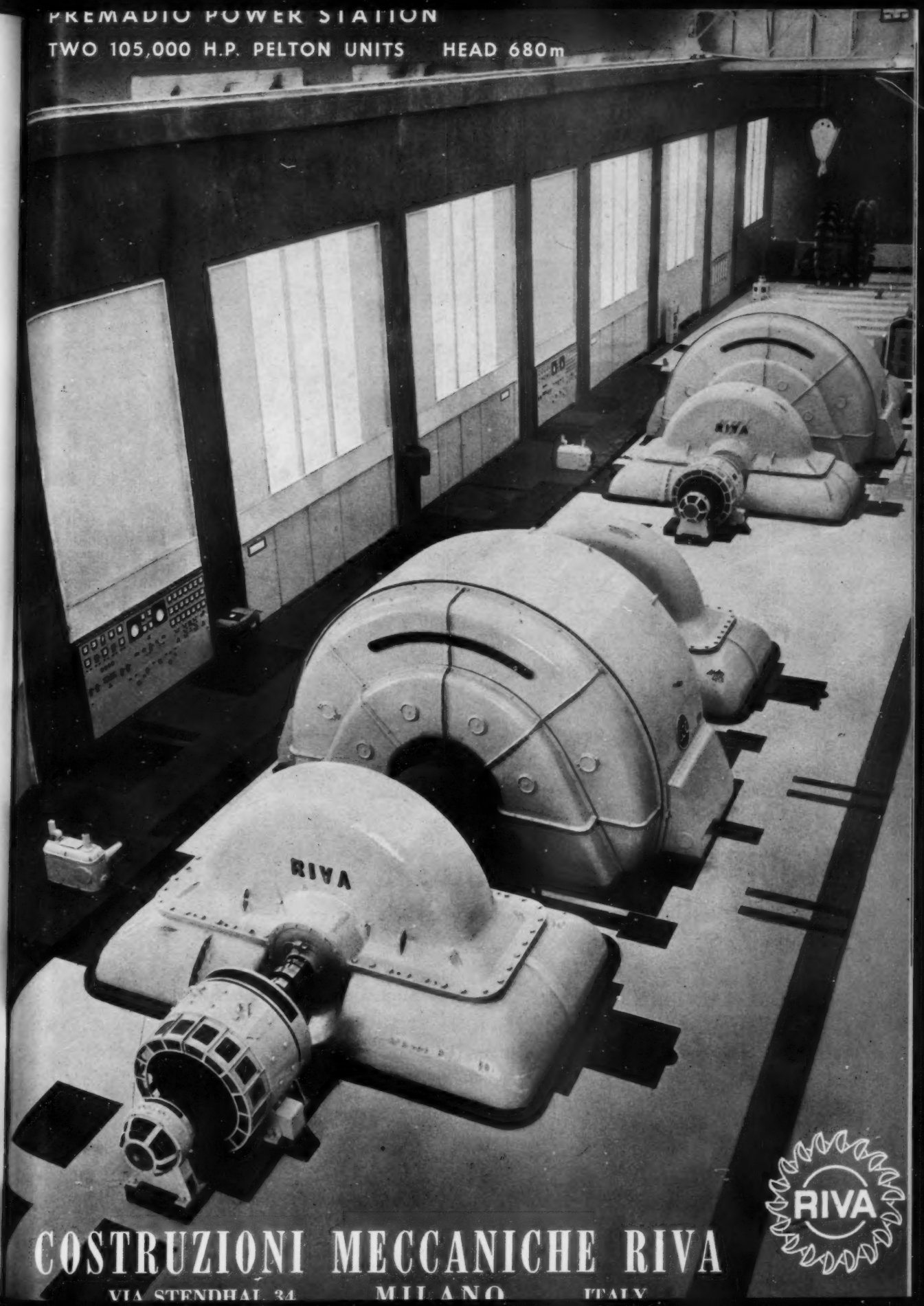
# ALL THE WORLD WIDE . . . 80 YEARS DEEP

RapieR engineers can draw on 80 years' world-wide experience when designing, manufacturing and installing hydraulic sluice structures for power stations, turbine intakes, draft tubes, dam culverts and spillways — as well as for irrigation, flood control and water supply. This experience added to the comprehensive technical resources of the Ransomes and Rapier works at Ipswich is always available against enquiries



RAPIER

**RANSOMES AND RAPIER LIMITED**
Waterside Works, Ipswich · Tel. 56383
Telegrams & Cables: Sluice Ipswich Telex
A Newton Chambers Company


PREMADIO POWER STATION
TWO 105,000 H.P. PELTON UNITS HEAD 680m
RIVA
RIVA
COSTRUZIONI MECCANICHE RIVA
VIA STENDHAL 34 MILANO ITALY
RIVA

# "WOOD STAVE for HYDRO-ELECTRIC PIPELINES"

In rugged mountain and fertile valley this versatile conduit has demonstrated unparalleled economy and ease of construction.

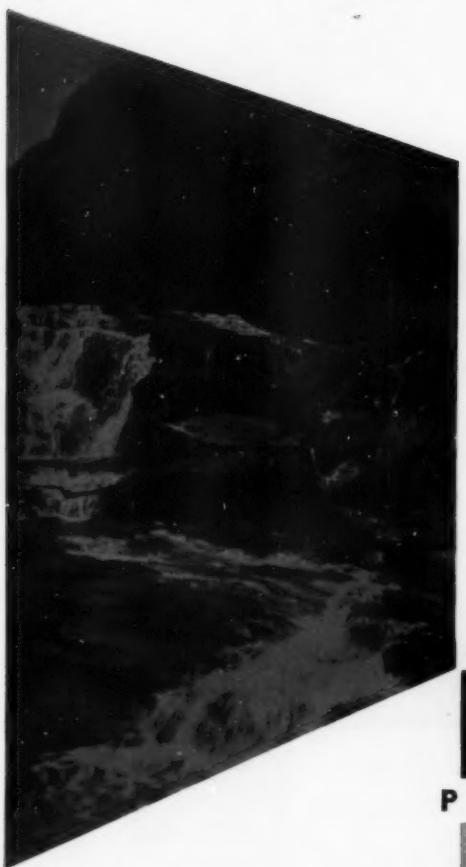
Wood stave pipe is assembled from manufactured components easily shipped to the most remote sites. It can be constructed over the most difficult terrain and complex contours by local labour. For these reasons, wood stave pipe is frequently the only economic solution available for penstocks, high-line conduits or irrigation projects.

Our recent publication: *CONTINUOUS STAVE WOOD PIPE*, reveals details of history, uses, construction and maintenance, together with design data and flow tables.

Write for your copy.

**CANADIAN WOOD PIPE & TANKS LIMITED**

550 Pacific Street,
Vancouver 2, British Columbia,
Canada



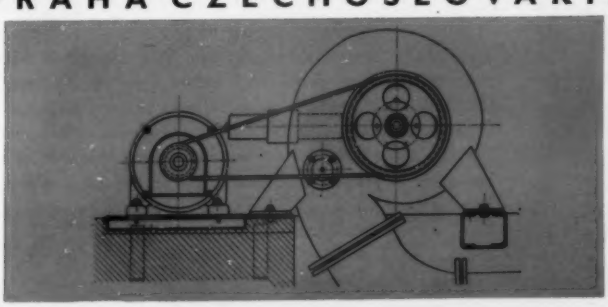
# SMALL WATER POWER PLANTS

*for a head of 4 m up to 26 m*
*output of 5 kW up to 120 kW*

**Very advantageous due to their simple construction. Fully automatic. Operate with the smallest water streams.**

**TECHNOEXPORT**

**PRAHA CZECHOSLOVAKIA**



no exaggeration

*Using reputation as the bait, Victor Drill Steels hooked a sizeable order with The Mitchell Construction Co. Ltd. for a Scottish Hydro Electric project. Hauling in the footage to the tune of 3½ million feet in 12 months proved a tall order—but no tall story. Some fish!*

Victor

DRILL STEELS

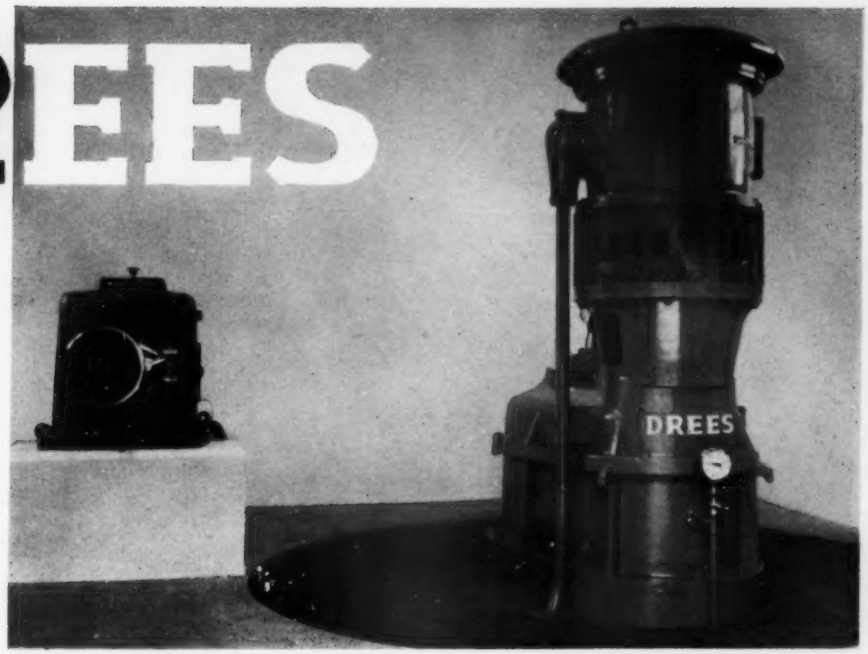
VICTOR PRODUCTS (WALLSEND) LIMITED

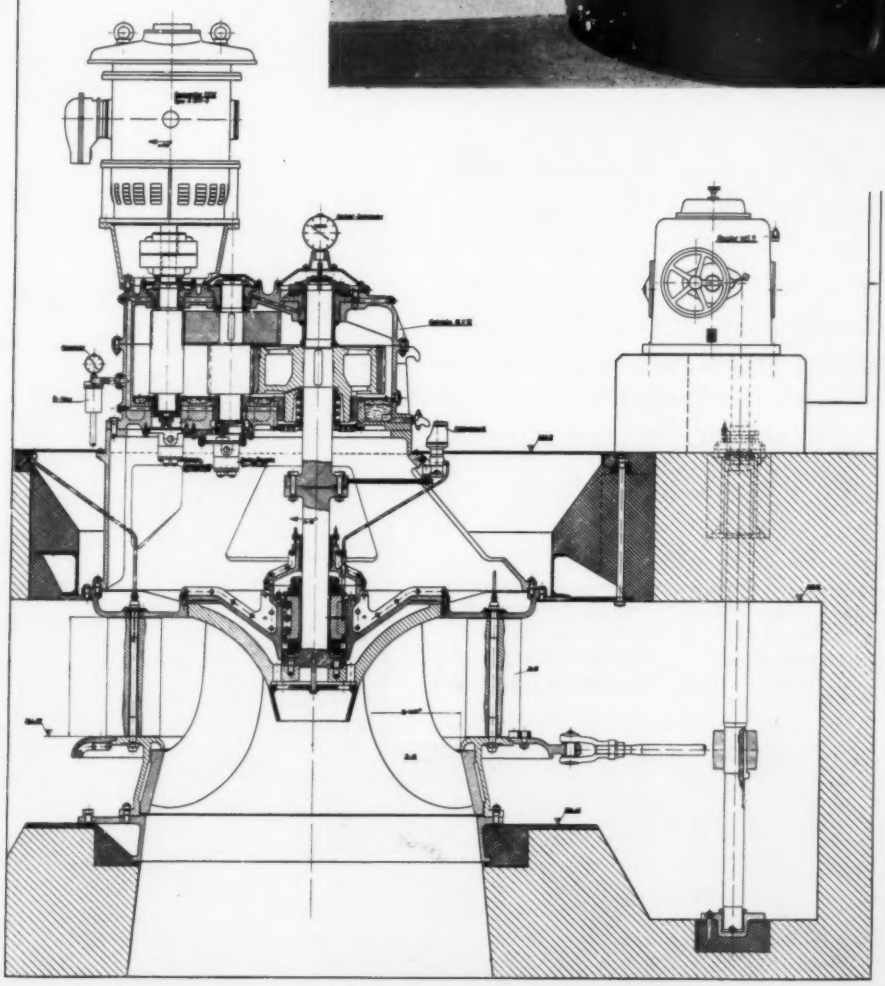
**VICTOR STACCATI VELOCIUS STRATUM**

Colloquially known as 'Rockbiter' this species is noted for an uncommonly hard proboscis. When agitated, displays a curious affinity for rock, into which it burrows at prodigious speed. Diet: Limestone, Granite, Basalt and most minerals. Particularly fond of Pyrites. Usual habitat is any mineral region where its natural food is abundant. A gregarious creature, it is usually found in groups of from four to eight, although independent specimens have been observed.

WALLSEND, ENGLAND. TELEPHONE: WALLSEND 628331 6 TELEGRAMS: 'VICTOR' WALLSEND

# DREES



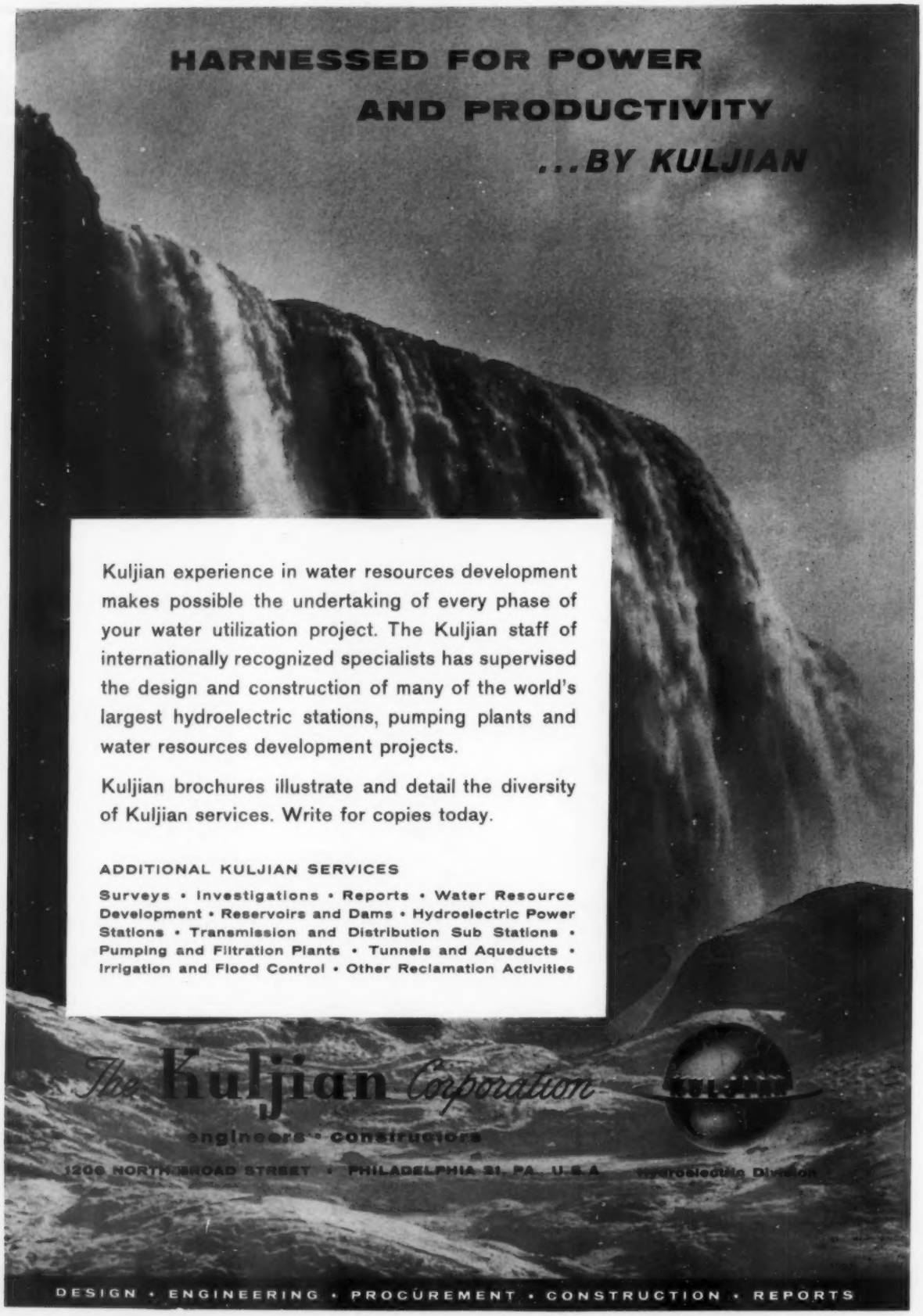
**DESIGNS AND CONSTRUCTS:**

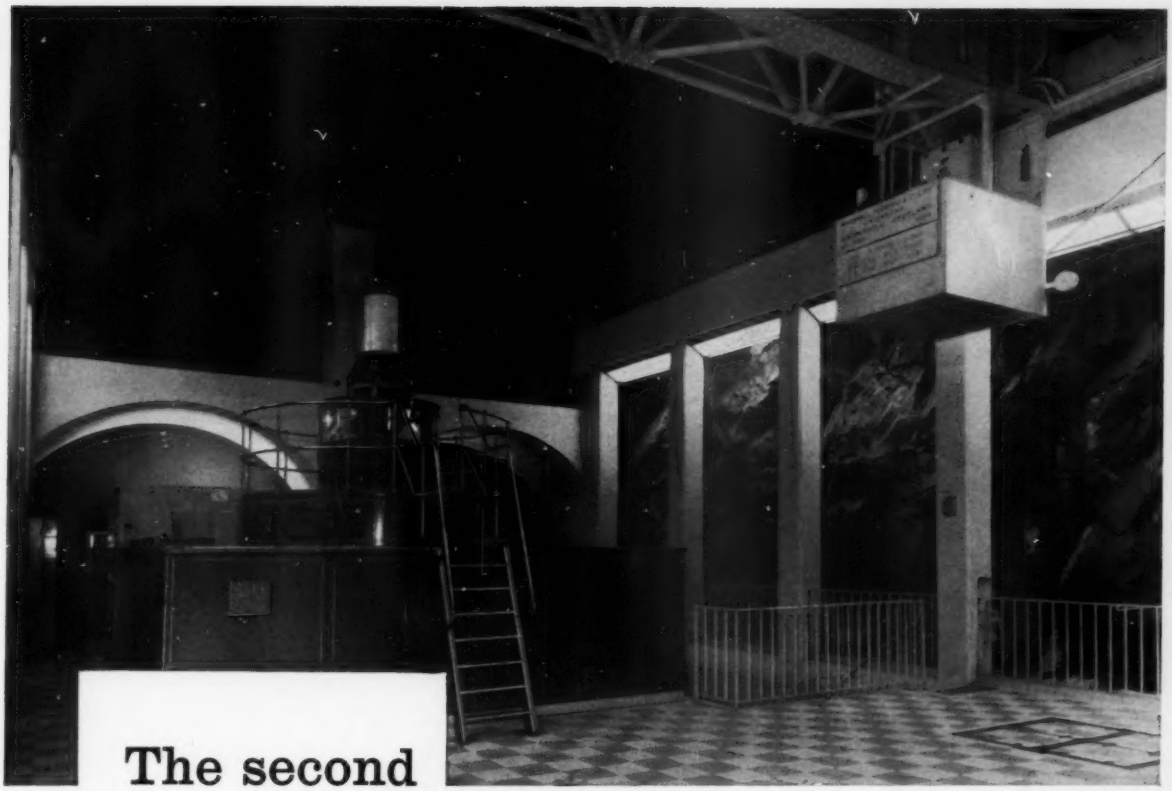
FRANCIS,
KAPLAN,
AND
PELTON
TURBINES
WITH HORIZONTAL AND VERTICAL SHAFTS

HYDRAULIC SPEED, HEAD WATER LEVEL AND SAFETY GOVERNORS

FLOW CONTROL EQUIPMENT GEARS

**DREES + CO. GMBH** WERL, WESTFALEN WESTERN GERMANY


HARNESSED FOR POWER
AND PRODUCTIVITY
...BY KULJIAN
Kuljian experience in water resources development makes possible the undertaking of every phase of your water utilization project. The Kuljian staff of internationally recognized specialists has supervised the design and construction of many of the world's largest hydroelectric stations, pumping plants and water resources development projects.
Kuljian brochures illustrate and detail the diversity of Kuljian services. Write for copies today.
ADDITIONAL KULJIAN SERVICES
Surveys • Investigations • Reports • Water Resource Development • Reservoirs and Dams • Hydroelectric Power Stations • Transmission and Distribution Sub Stations • Pumping and Filtration Plants • Tunnels and Aqueducts • Irrigation and Flood Control • Other Reclamation Activities
The Kuljian Corporation
engineers • constructors
1206 NORTH BROAD STREET • PHILADELPHIA 21, PA., U.S.A.
Hydroelectric Division
DESIGN • ENGINEERING • PROCUREMENT • CONSTRUCTION • REPORTS



# The second underground power station

The St. Fillans Power Station is the second major power station constructed completely underground in the British Isles. Both this and the first major underground station were included in contracts carried out by the Mitchell Construction Co. Ltd.
St. Fillans Power Station forms part of the St. Fillans section of the North of Scotland Hydro-Electric Board's Breadalbane scheme. Mitchell Construction were responsible for the construction on this scheme of two generating stations, 19 miles of tunnelling and numerous intake works and pipe aqueducts.

*Consulting Engineers: Sir M. MacDonald & Partners*

**MITCHELL CONSTRUCTION**

*Building and Civil Engineering Contractors*

**THE MITCHELL CONSTRUCTION COMPANY LTD**

*Wharf Works, Peterborough*

P.3040

## AIR BUBBLES HOLD BACK THE ICE

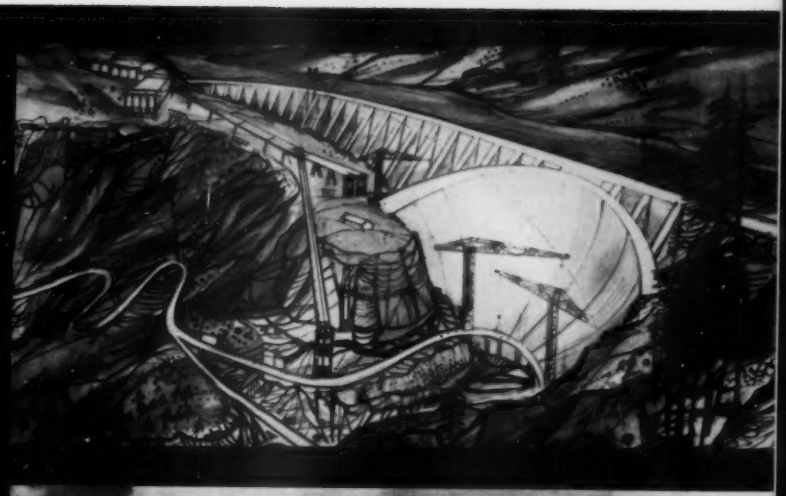
Compressed air is power. Ice-free channels through Stockholm's waterways have been kept clear by air pumped from Atlas Copco compressors through perforated underwater pipes. In Canada and in U.S.A., in Greenland and in Sweden, dock and harbour authorities are finding the Atlas Copco Air Bubbler System essential for easing the costly, paralysing grip of ice in northern harbours.

Wherever you go you will find Atlas Copco equipment at work; portable compressors for a new Middle East pipeline, sprayguns at Jaguar's Coventry works, loaders in the German coalmines or rock drills for Ghana's new Tema harbour project. The company's air tools are used to build Sud-Aviation's Caravelle. Philips, Vauxhall and I.C.I. have chosen Atlas Copco compressors for applications where continuous air supplies are vital.

With companies or agents in more than 100 countries, Atlas Copco is the world's largest organisation specialising in this field. Wherever you are, the international Atlas Copco Group will advise you on the application of compressed air and provide a complete after-sales service.

## MORE POWER FOR FRANCE

To Electricite de France the Savoy Alps mean power. The Roselend Valley project, for example, involves building two dams and a 476,000kw power station – the most powerful in the country – which will increase France's power reserves by 1,000 million kw a year. Atlas Copco equipment has been used almost everywhere at Roselend – the main tunnels being drilled with more than 100 Atlas Copco rock drills and many thousands of Sandvik Coromant steels.



## THROUGH THE HEART OF MONT BLANC

On completion of the seven-mile Mont Blanc road tunnel motorists will find Paris 137 miles nearer Turin. For the first time they will be provided with an Alpine link between France and Italy open all the year round. More than half the tunnel is being driven from the Italian side using Atlas Copco rock drills fitted with Sandvik Coromant drill steels and powered by Atlas Copco compressors.

## OIL PROSPECTING IN THE SAHARA

In the continuing search for hidden oil resources in the Sahara, seismic prospecting techniques are often employed. Many prospecting companies use Atlas Copco equipment to drill the hundred or more sounding holes for each blasting pattern. Typical of the units used for this work is the Atlas Copco truck-mounted compressor – air cooled for desert operations – driving a chain-fed rock drill with Sandvik Coromant drill steels.

IC/2

**Atlas Copco** puts compressed air to work for the world

SALES AND SERVICE IN OVER 100 COUNTRIES

# the bigger the better

The Valve illustrated, 42" diameter, is one of a large order supplied to the Greek Water Board.

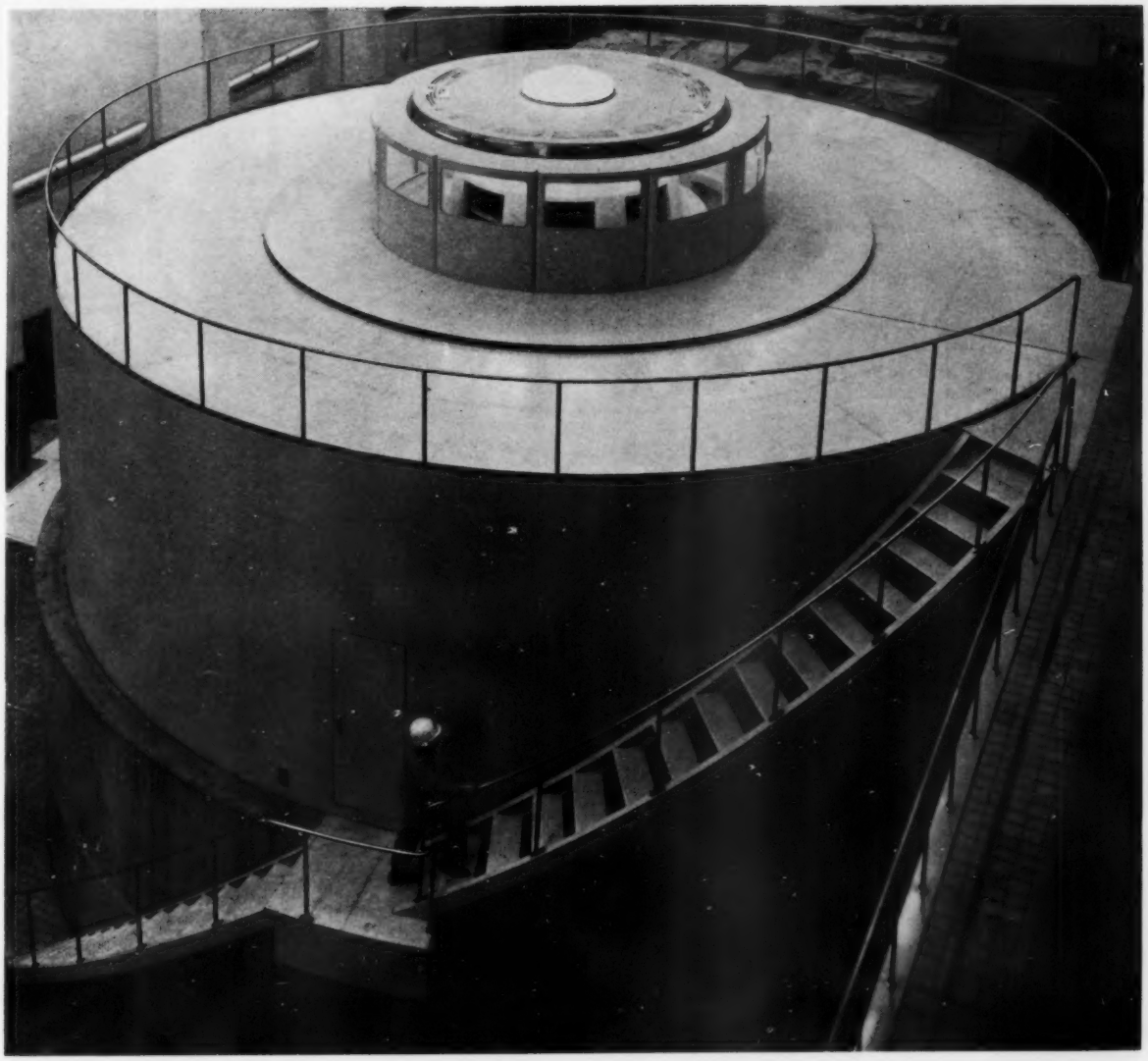
In the 2" bore size, the face to face dimension of a Cockburn-Rockwell Butterfly Valve is 1¾". With a 17¼" bore, the valve is 4" face to face. In the 35¼" size, the economy in space is even more marked—only 8½" of the pipe run is occupied by the valve. Cockburn-Rockwell Butterfly Valves are the most compact form of pipeline control, and this feature becomes more and more appreciable as the size increases. Valves are currently being manufactured with Bores up to 60" Diameter.

## COCKBURN-ROCKWELL BUTTERFLY VALVES

COCKBURNS LTD
Cardonald Glasgow SW1

**CWR** Certain Cockburn-Rockwell Butterfly Valves including designs with spool liners, are manufactured to a common standard in Britain, United States, France, Holland & South America. Service and interchangeable spare parts for the CWR range are available in all these countries. Full information on request.

105,000 kVA Water-Wheel Generators



*A LOT OF LIFE'S COMFORTS START AT*

# MITSUBISHI ELECTRIC

When you think of giant generators, you rarely think of their vital part in making this world a more comfortable place to live in. Yet Mitsubishi Electric's great generators and transformers, plus many large and small home appliances all do just that..... every day in countless ways. Backed by a long history of outstanding achievements, distinguished by the famous Mitsubishi Brand. Do think about it the next time you see the THREE DIAMONDS on an electric appliance.

**MITSUBISHI ELECTRIC MANUFACTURING COMPANY**

**Head Office: Tokyo Building, Marunouchi, Tokyo** **Cable Address: MELCO TOKYO**

# ALLIS-CHALMERS

**The two Bascule gates at the Lake deForest Dam,** Spring Valley Waterworks & Supply Co., N. Y., each 50 feet long by 5 feet high. A-C also provided 24- and 12-inch **Howell-Bunger** free-discharge valves, installed in the left-hand abutment, to regulate minimum flow requirements.

## Bascule gates provide the extra storage you need...

## save 80 to 90% of new dam costs

You can add impressive capacity and higher head to your dam by equipping it with *Bascule* gates . . . at a fraction of the cost of building a dam of equivalent capacity. *Bascule* gates are readily installed for both new and existing reservoirs, frequently in less than 9 months (compared to the 2 years or more needed for new dam construction).

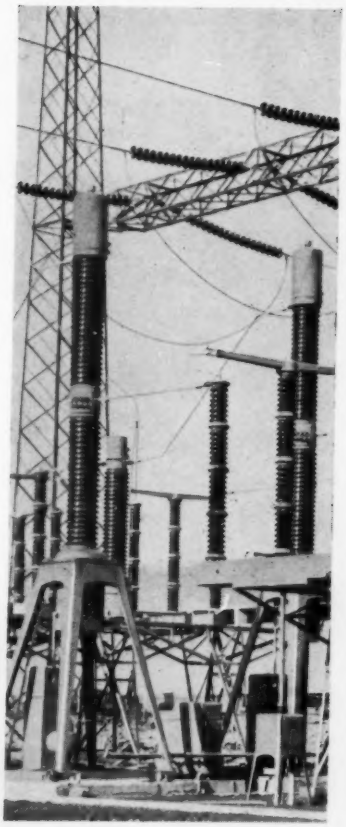
By their very nature, these gates add capacity without requiring overhead structures and without increasing flood level, a dual problem not resolved with other gates. Since they discharge over the top, level regulation is facilitated . . . ice goes over the top, so they can function as ice breakers.

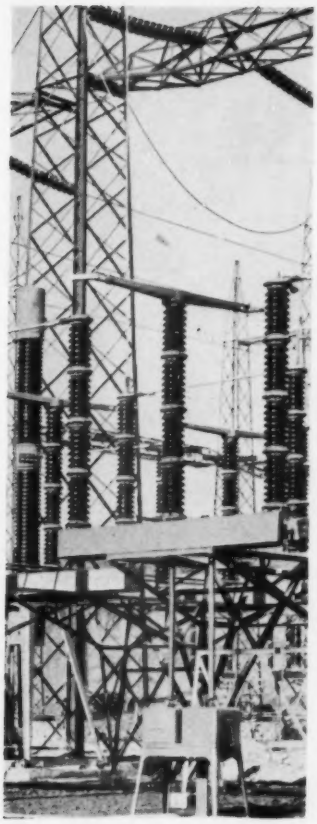
There's added safety too: extreme water pressure can initiate hydraulic lowering of the gate to maintain safe upstream or reservoir water levels. The result: a fail-safe installation. Or, where downstream conditions are the concern, a mechanical operator can be employed.

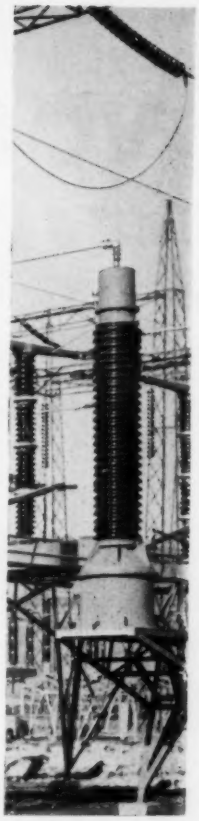
• • •

*These unique Bascule gates are one more exclusive from Allis-Chalmers . . . proof again that A-C is your surest source of water control equipment designed to stretch investment dollars. For details, contact your local A-C representative or write to* **Allis-Chalmers,** *Hydraulic Division, York, Pennsylvania.* A-1417

Bascule and Howell-Bunger are Allis-Chalmers trademarks.







OFFICINE ELETTROMECCANICHE GALILEO

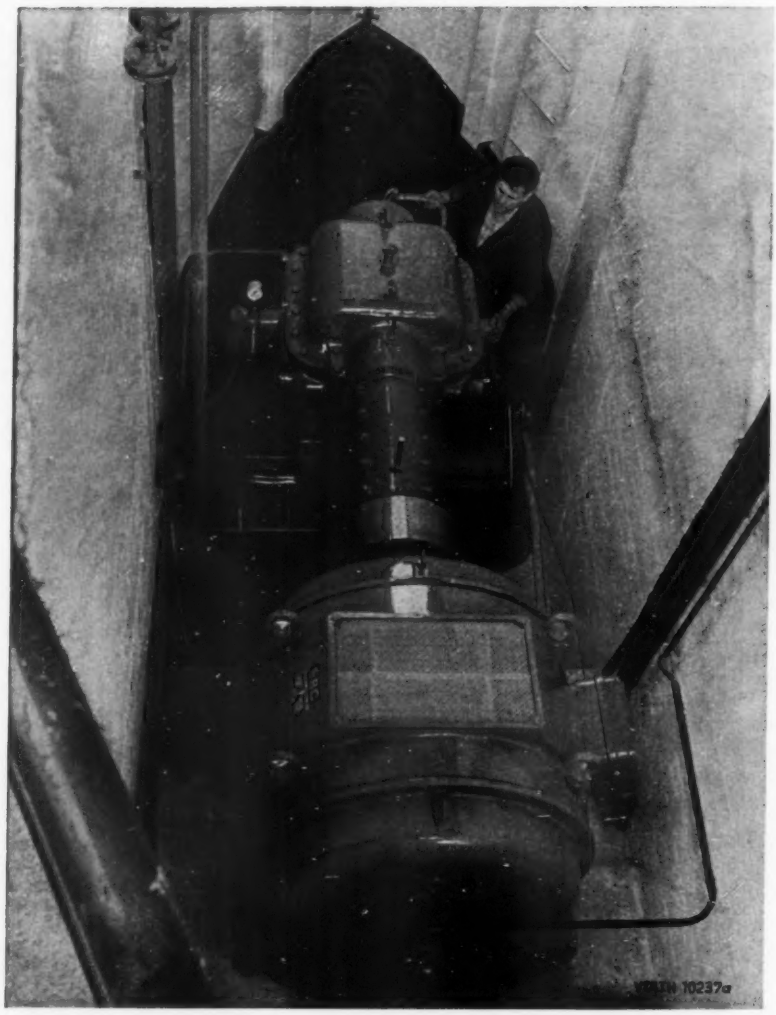
FOREIGN SALES MANAGEMENT : MILANO VIA LARGA 26 (ITALY)

ELECTRICAL EQUIPMENT

CIRCUIT BREAKERS
INSTRUMENT TRANSFORMERS
ISOLATING SWITCHES
BUSHING INSULATORS
SWITCHBOARDS
METAL-CLAD SWITCHGEAR

FOR MEDIUM, HIGH
AND ULTRA-HIGH VOLTAGES

# VOITH

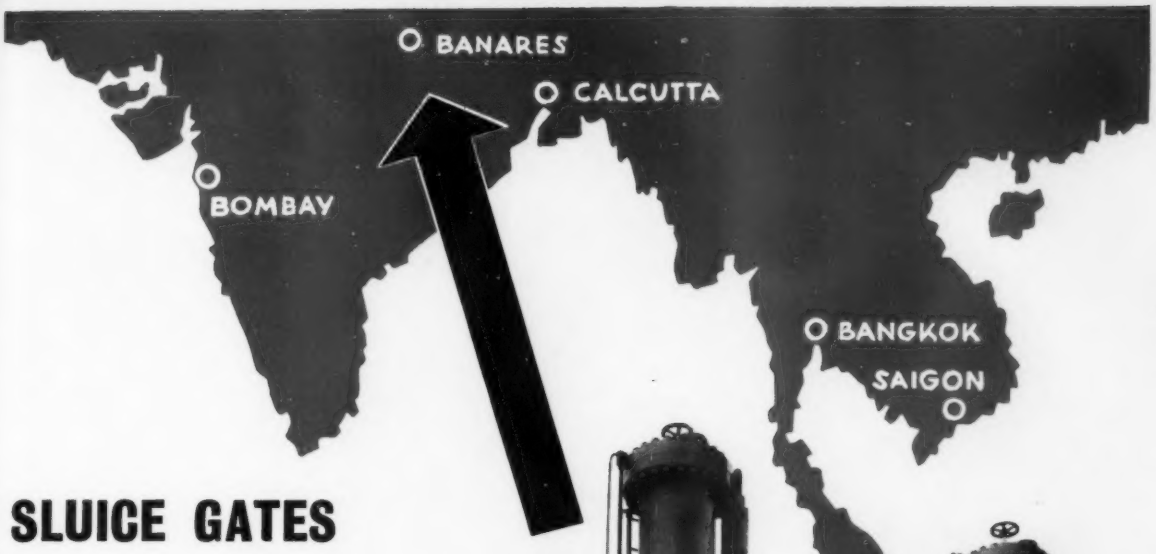


## A typical low-head machine

## - a tubular turbine

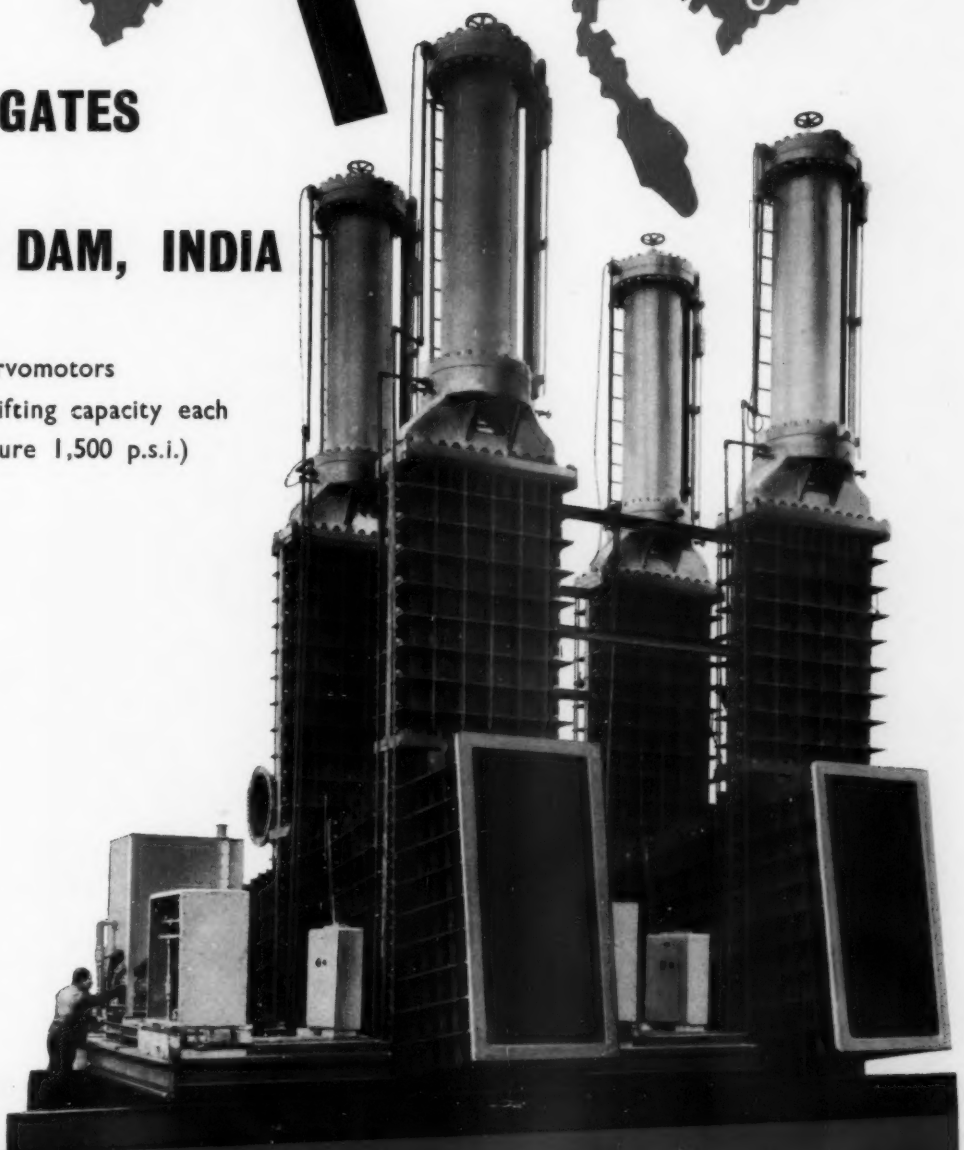
with adjustable runner blades as supplied by Voith-Heidenheim for the city of Gaggenau in Southern Germany: the turbine shaft drives a spur gear unit and a generator which are accommodated in a hollow pier so as to be readily accessible for maintenance (see photo). This 655-hp, 10-ft turbine discharges 675 cft/sec. In connection with the river Mosel canalization scheme, Voith will supply for the Lehmen power station two 6,300-hp, 17-ft head, 85-rpm tubular turbines and two 7,000-hp tubular pump-turbines (reversible turbines) which will deliver against a head of 28 ft. The diameter of the runners is 15 ft. – Why not consult Voith?

**J. M. VOITH GMBH · HEIDENHEIM (BRENZ) · GERMANY**




# SLUICE GATES for RIHAND DAM, INDIA

Oilhydraulic Servomotors
of 500,000 lbs lifting capacity each
(Working pressure 1,500 p.s.i.)

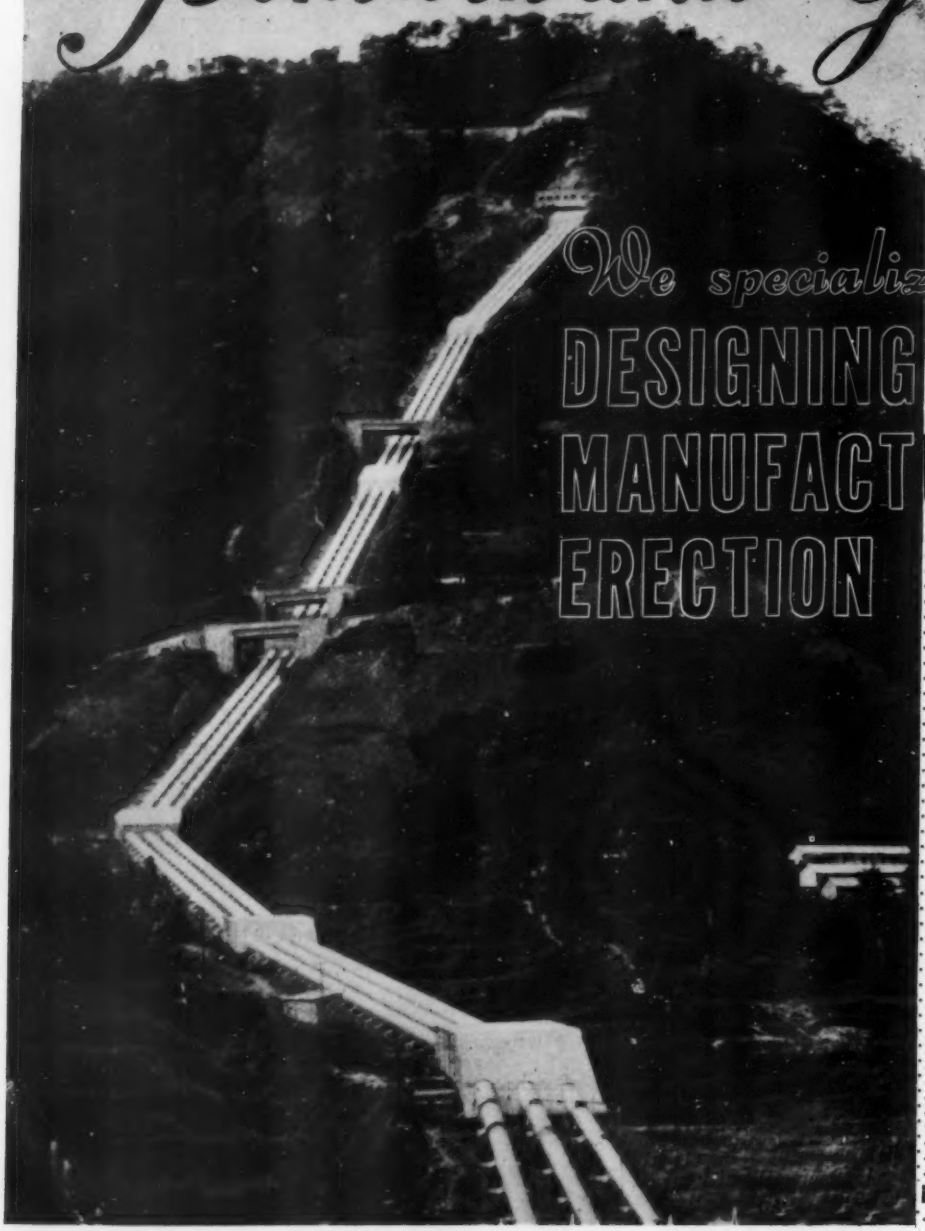


## WAAGNER-BIRÓ A.G.

WIEN GRAZ

Head Office: Vienna V., Margaretenstrasse 70 / Austria

# Penstock and Gate



*We specialize in . . .*

DESIGNING
MANUFACTURING
ERECTION

Established: 1904

## SAKAI IRON WORKS CO., LTD.

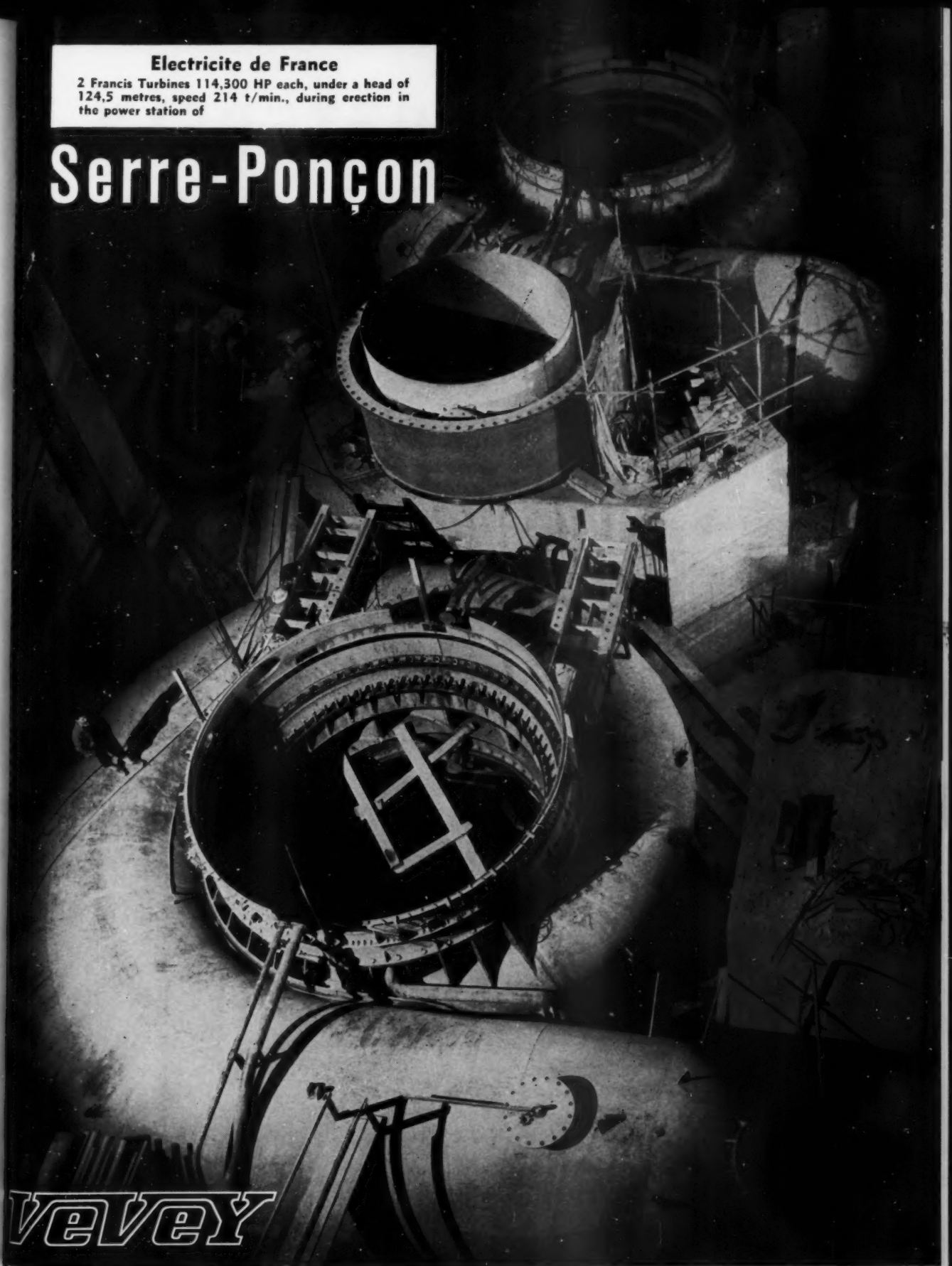
HEAD OFFICE: NISHI, 6-CHOME, TSUMORI-CHO, NISHINARI-KU, OSAKA, JAPAN CABLE ADDRESS: "SAKATETSU OSAKA"

TOKYO OFFICE: NIHONBASHI-GOFUKUBASHI, CHUO-KU, TOKYO, JAPAN CABLE ADDRESS: "SAKATETSU TOKYO"

**Electricite de France**

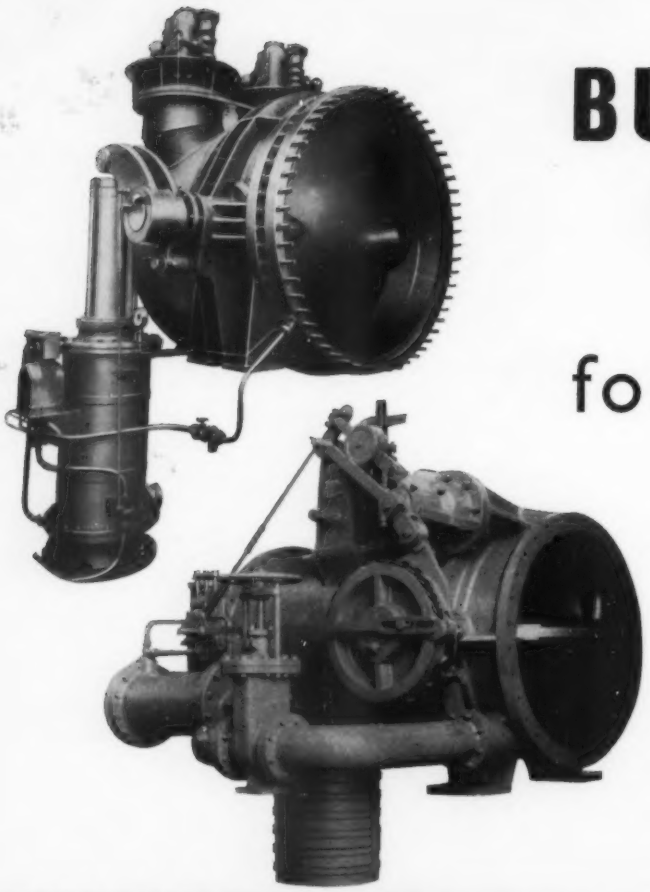
2 Francis Turbines 114,300 HP each, under a head of 124,5 metres, speed 214 t/min., during erection in the power station of

# Serre-Ponçon



**Vevey Engineering Works Ltd.**
Vevey (Switzerland)

in collaboration with our French licensee:
Cie des Ateliers et Forges de la Loire, St-Chamond (Loire)



# BUTTERFLY VALVES

## for Pipelines

Large butterfly valves for portal or emergency shut-off service in hydro-electric pipelines are a Glenfield specialty.

The butterfly type of valve is ideal for such purposes, as its closing characteristics give very favourable rate of retardation of flow during closure. Thus, it may be shut in a minimum time at constant speed whilst keeping upstream pressure rise within prescribed limits.

Illustrated are a 96 in. dia. hydraulically-operated automatic self-closing portal valve with anti-vacuum valves; and a 42 in. dia. weight-actuated automatic emergency isolating valve.

Six single-phase transformers, cooled by separately mounted radiators, forming two 75 MVA three-phase banks, ratio 11 ± 5% / 260 kV. These transformers have been supplied to C.E.B. (Consorzio Elettrico del Buthier), Turin, Italy, for the Valpelline power station; and they have the highest voltage in the Aosta Valley power system.

**società nazionale delle officine di**

# savigliano

**Corso Mortara 4 - TORINO** (ITALIA)

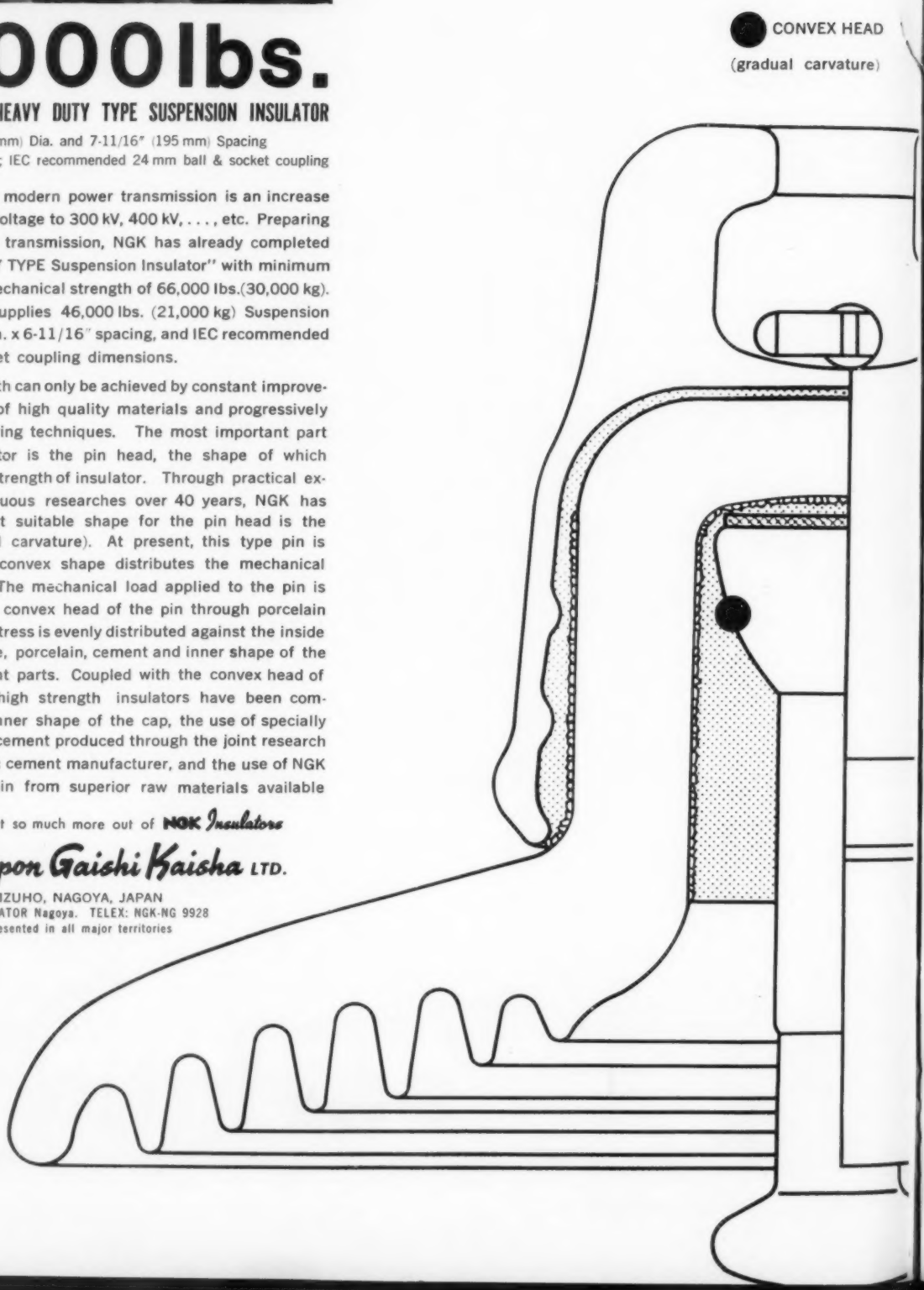
# 66,000lbs.

## (30,000 kg) EXTRA HEAVY DUTY TYPE SUSPENSION INSULATOR

12-5/8″ (320 mm) Dia. and 7-11/16″ (195 mm) Spacing
NGK Cat. No. CA-590ND ; IEC recommended 24 mm ball & socket coupling

The general trend of modern power transmission is an increase in the transmission voltage to 300 kV, 400 kV, . . . , etc. Preparing for these EHV power transmission, NGK has already completed "EXTRA HEAVY DUTY TYPE Suspension Insulator" with minimum guaranteed electro-mechanical strength of 66,000 lbs.(30,000 kg). Besides this, NGK supplies 46,000 lbs. (21,000 kg) Suspension Insulators with 11″ dia. x 6-11/16″ spacing, and IEC recommended 20mm ball and socket coupling dimensions.

This extra-high strength can only be achieved by constant improvement in design, use of high quality materials and progressively advanced manufacturing techniques. The most important part of suspension insulator is the pin head, the shape of which controls mechanical strength of insulator. Through practical experiences and continuous researches over 40 years, NGK has proven that the most suitable shape for the pin head is the convex head (gradual carvature). At present, this type pin is NGK standard. The convex shape distributes the mechanical stress most evenly. The mechanical load applied to the pin is transmitted from the convex head of the pin through porcelain and cement, and the stress is evenly distributed against the inside of the cap. Therefore, porcelain, cement and inner shape of the cap are also important parts. Coupled with the convex head of the pin, these extra-high strength insulators have been completed by improved inner shape of the cap, the use of specially prepared high quality cement produced through the joint research of NGK and a specific cement manufacturer, and the use of NGK high strength porcelain from superior raw materials available in Japan.




You get so much more out of **NGK** *Insulators*

**Nippon Gaishi Kaisha LTD.**

MIZUHO, NAGOYA, JAPAN
Cable: INSULATOR Nagoya. TELEX: NGK-NG 9928
Represented in all major territories

PLAN ORGANIZATION
OF IRAN GOVERNMENT

DEVELOPMENT
& RESOURCES
CORPORATION
NEW YORK

HYDROELECTRIC PROJECT
ON THE DEZ RIVER—IRAN

CIVIL WORKS CARRIED OUT BY IMPRESIT-GIROLA-LODIGIANI IN JOINT VENTURE WITH K.G.T.—TEHERAN

# IMPRESIT-GIROLA-LODIGIANI

**S. P. A.**

**MILANO-ITALY**

VIA GAETANO NEGRI, 4

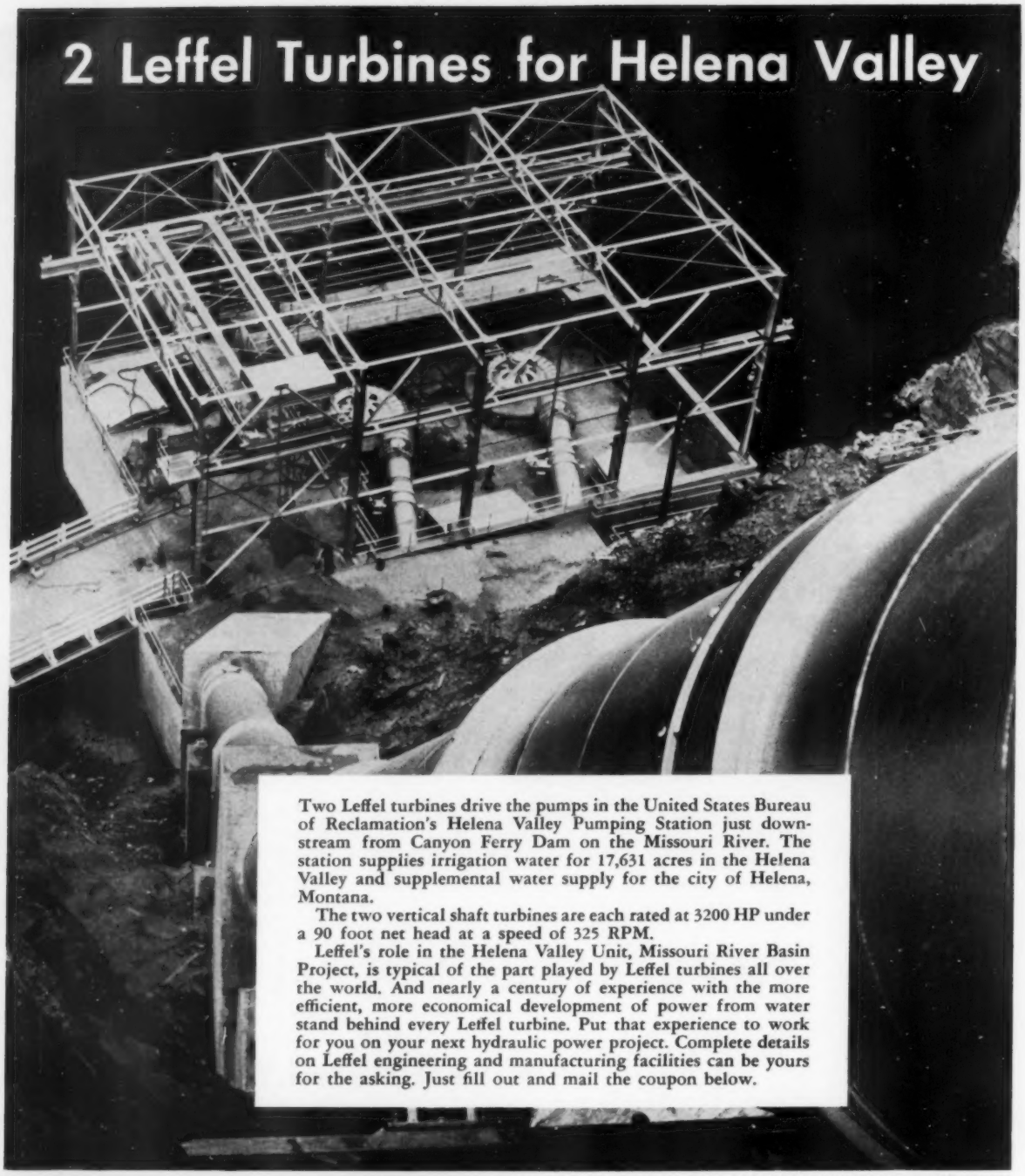
PARENT FIRMS

**IMPRESE ITALIANE ALL'ESTERO-IMPRESIT-S.P.A.**

**IMPRESA UMBERTO GIROLA**

**IMPRESA ING. LODIGIANI S.P.A.**

# 2 Leffel Turbines for Helena Valley



Two Leffel turbines drive the pumps in the United States Bureau of Reclamation's Helena Valley Pumping Station just downstream from Canyon Ferry Dam on the Missouri River. The station supplies irrigation water for 17,631 acres in the Helena Valley and supplemental water supply for the city of Helena, Montana.

The two vertical shaft turbines are each rated at 3200 HP under a 90 foot net head at a speed of 325 RPM.

Leffel's role in the Helena Valley Unit, Missouri River Basin Project, is typical of the part played by Leffel turbines all over the world. And nearly a century of experience with the more efficient, more economical development of power from water stand behind every Leffel turbine. Put that experience to work for you on your next hydraulic power project. Complete details on Leffel engineering and manufacturing facilities can be yours for the asking. Just fill out and mail the coupon below.

**THE JAMES LEFFEL & CO.**

FOUNDED IN 1862

MORE EFFICIENT HYDRAULIC POWER FOR 99 YEARS

**FREE LITERATURE** 1109-E

**THE JAMES LEFFEL & COMPANY**
**DEPT. W SPRINGFIELD, OHIO, U.S.A.**

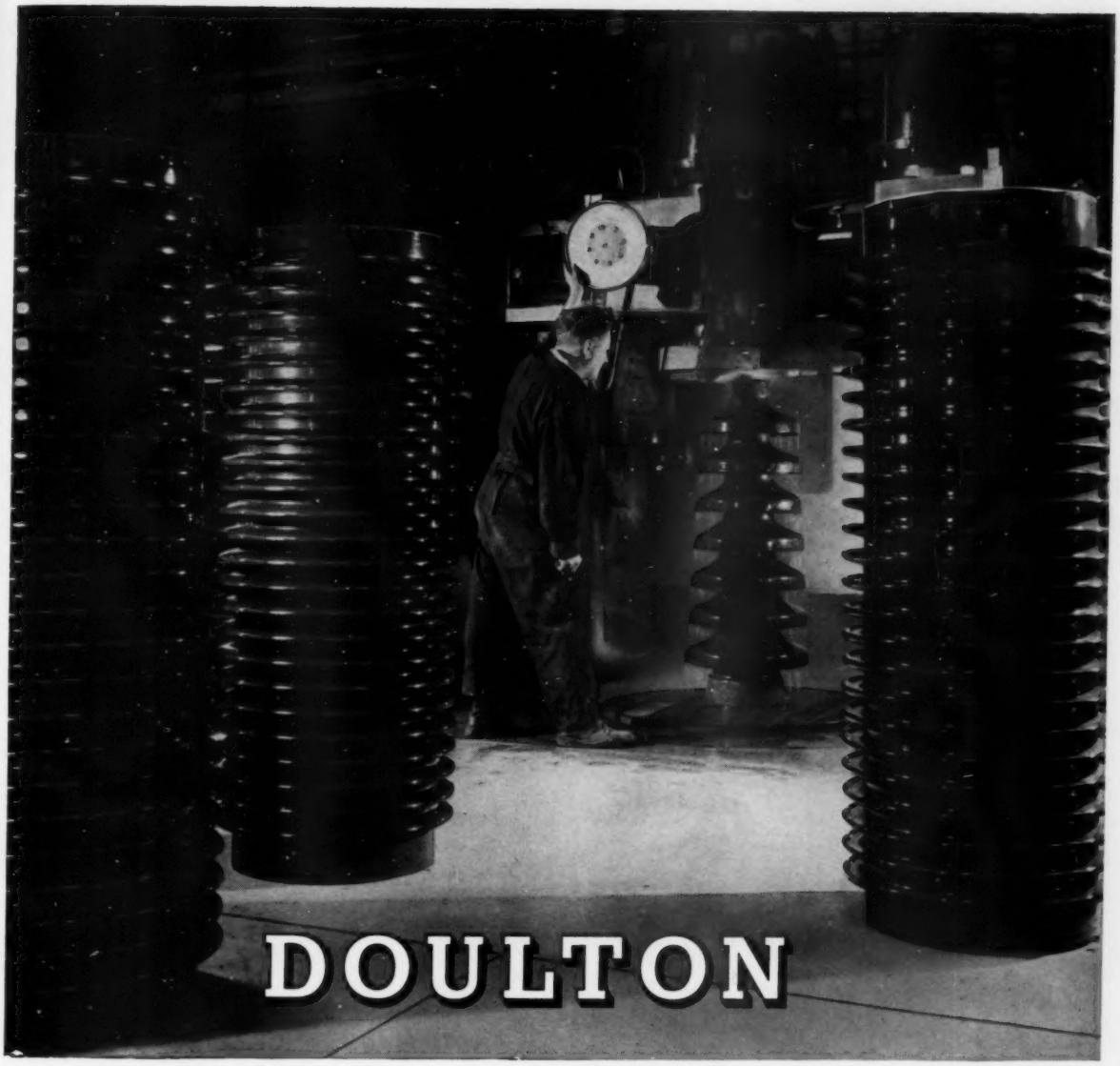
☐ Please send me more information on Leffel hydraulic turbines.

☐ Please have your representative call.

Name_____ Title_____

Company_____

Street_____ City_____ State_____



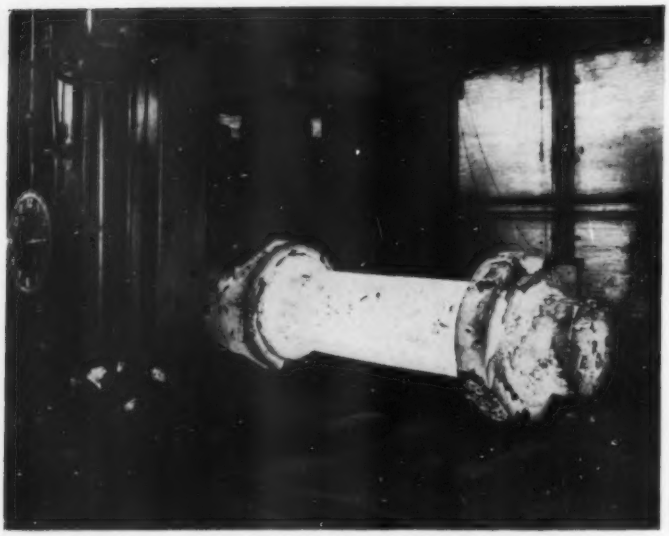

# INSULATORS

A 132 kV Porcelain anti-fog cable ceiling end being ground to dimensional tolerances, as supplied to Pirelli General Cable Works Ltd. for use on C.E.G.B. contracts.

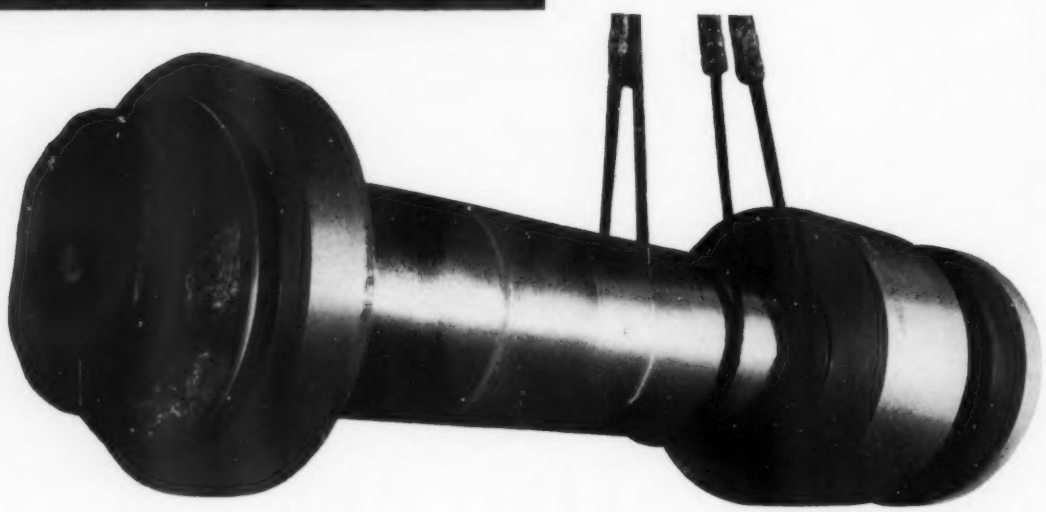
The three large 180 kV Porcelain bushings in the foreground are part of a consignment for the Canadian General Electric Co. Grinding and routine testing are the final stages before shipment to Toronto.

**DOULTON INDUSTRIAL PORCELAINS LIMITED**

ROYAL DOULTON POTTERIES · WILNECOTE · TAMWORTH · STAFFS



**For many years ESC has been the leading supplier of steel forgings to many vital industries. Forgings in weights up to 175 tons are manufactured in our high quality carbon and alloy steels—single piece engineering units produced from ingots weighing up to 300 tons—and**



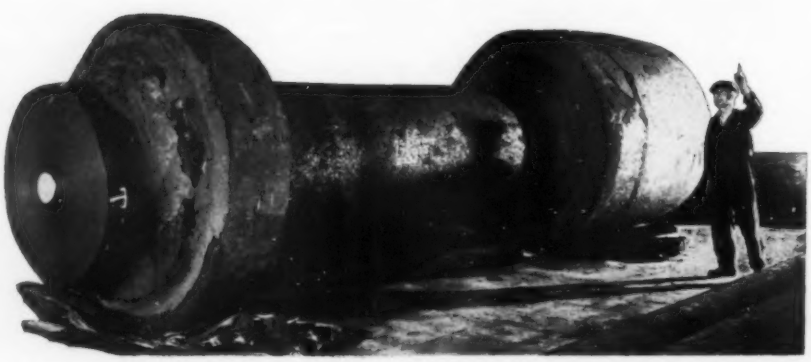
**other forgings from ingots 30 cwt. and upwards—for all branches of engineering.**

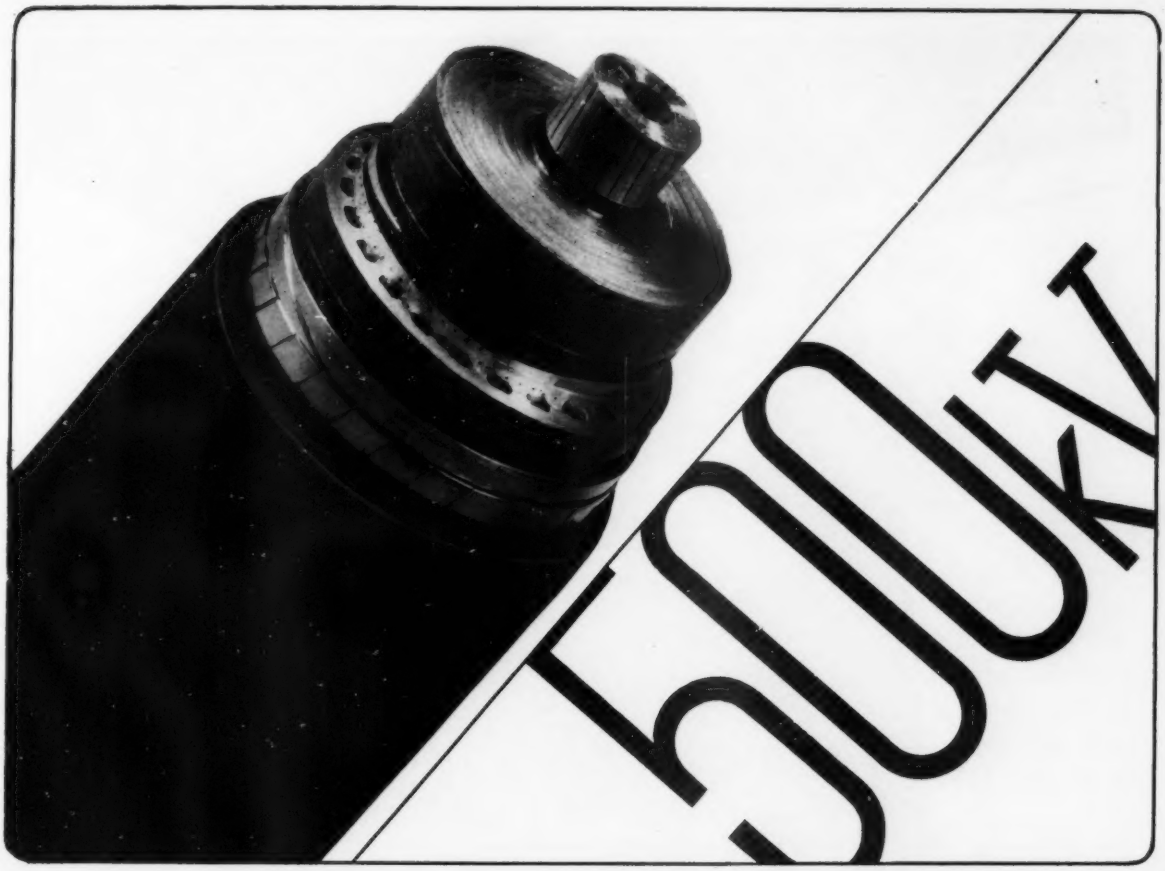
## ENGLISH STEEL FORGE AND ENGINEERING CORPORATION LTD.

**River Don Works, Sheffield**

A wholly owned subsidiary of English Steel Corporation Ltd.

*Illustrations show a forging operation under a 7,000 ton electro-hydraulic press, rough machined and black forged steel Turbine shafts, 22′ 11″ long, 3′ 8″ diameter with 6′ 2″ and 6′ 4″ diameter couplings—Weight as forged 111½ tons, rough machined 70 tons—for a modern hydro-electric power project.*






# *Ready for Tomorrow's Transmission Needs*

In keeping with the world trend toward a more extensive application of 400kV power transmission, Japan is now adopting the higher rating instead of the conventional 275kV as has been used in the past. This changeover has been reflected in intensified research activities at the ultra-high power transmission testing laboratory incorporated in our new plant at Hitaka. A recent technical tieup with the famous Swedish firm of Liljeholmens was yet another progressive step, and has already resulted in the development and successful testing of a 500kV class $1 \times 540mm^2$ OF cable. Tomorrow's 400kV era will find us ready, as usual, at Hitachi.

▲ *412 Sheets Paper Lapping Machine*

Hitachi, Ltd.
Tokyo Japan
Cable Address: "HITACHY" TOKYO

**One of the 4 Oerlikon Alternators, each of 72 000 kVA, 600 r.p.m. actually under erection in the Sils hydro-electric power station (Switzerland)**

**Oerlikon supply furthermore:**

**Transformers**
**Switchgear**
**Traction equipment**
**Rectifiers**
**Electrolyzers**
**Cyclotron magnets**

**Oerlikon Engineering Company • Zurich 50 (Switzerland)**

# 1901

We've seen some things in our time. The introduction of Micanite to Europe. Bushings for the National Grid. Working voltages rising to 380 kV and over. New resins; silicone, epoxide, melamine, PTFE, etc. New materials; copper faced laminates, glass fabric laminates, mica paper, etc. New applications in nuclear power stations, electrically propelled passenger liners, diesel-electric locomotives, automation, jet airliners, rockets—*all challenging the abilities of the electrical insulation engineer.*

Whatever the requirement, we have always done our best to meet the needs of the electrical industry with the finest insulation—we are going to go on doing just that in our next 60 years.

m and i

**the electrical insulation people**

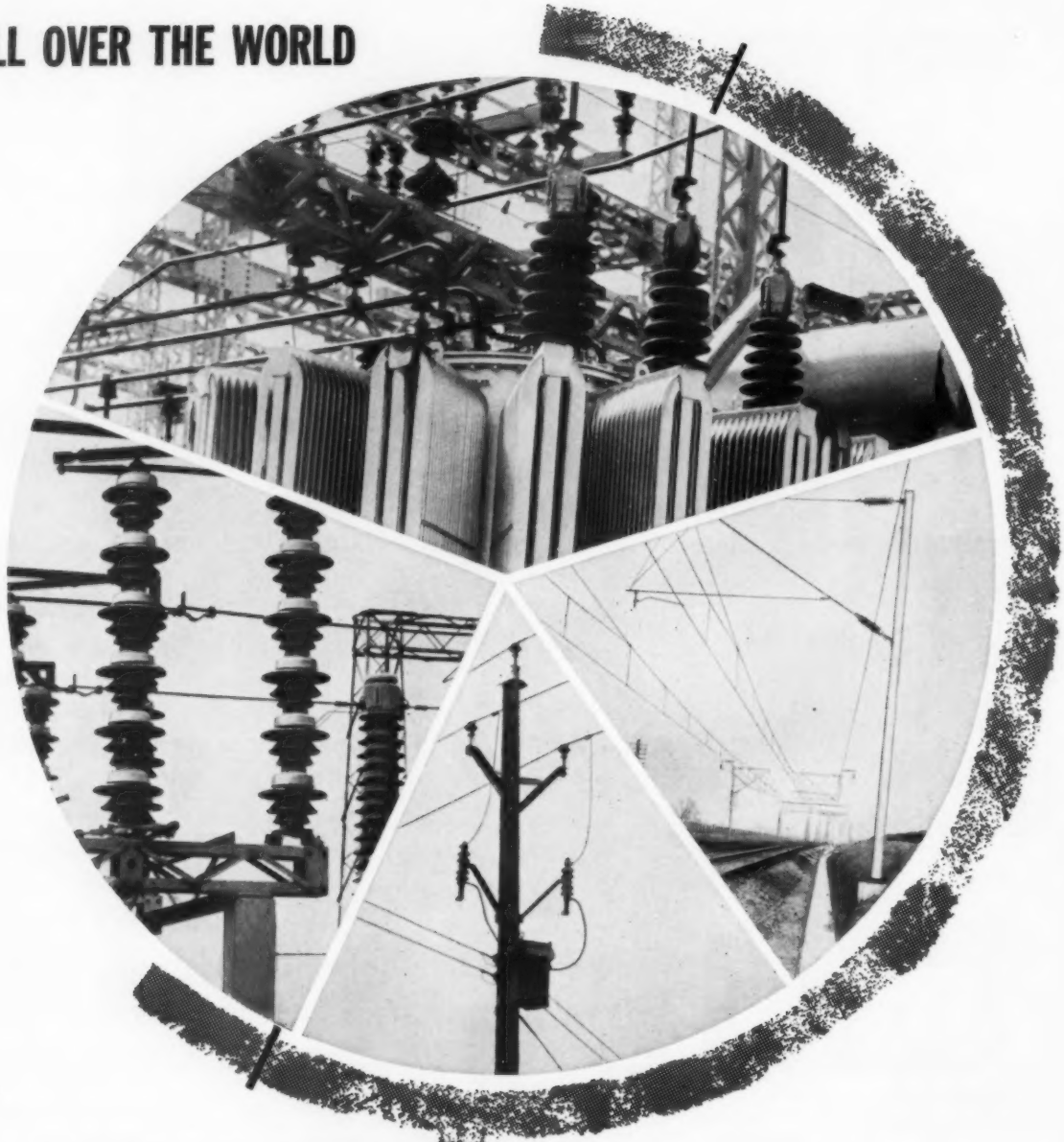
**THE MICANITE & INSULATORS CO., LTD.,**

**Empire Works, Blackhorse Lane, Walthamstow, London, E.17**

Telephone: Larkswood 5500. Telegrams: Mytilite, London, Telex. Telex: 25183.

# 1961

# ALL OVER THE WORLD



OVER-HEAD, UNDER-RAIL

# HIGH VOLTAGE INSULATORS

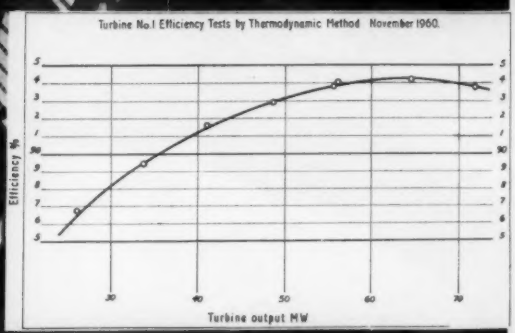
Overhead line insulators
Switchgear post insulators
Transformer bushings
Insulators for railway electrification
Custom-made porcelains

SP106

**STEATITE AND PORCELAIN PRODUCTS LTD.**

STOURPORT-ON-SEVERN, WORCS. TEL: STOURPORT 2271 GRAMS: STEATAIN, STOURPORT

# KVÆRNER

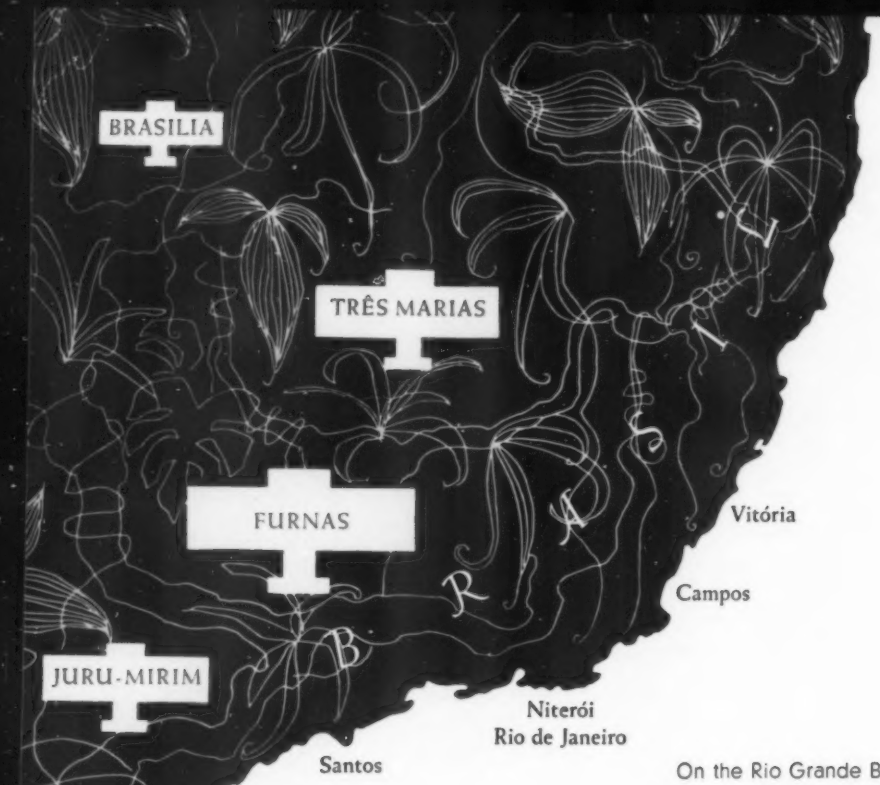



*Runner and shaft for Upper Vinstra Power Plant,*

*rated output 92,000 H.P., 428 rev./min., mean net head 320 metres.*

*Kvaerner Brug has delivered Francis turbines for heads up to 543 metres.*

**A. S. KVÆRNER BRUG, OSLO, NORWAY**




SIEMENS

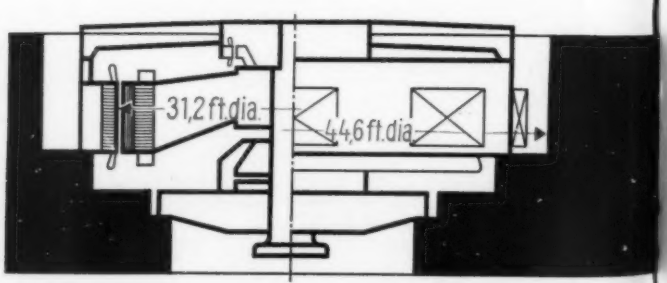
# 4 x 160,000* kVA Waterwheel Generators for Furnas

On the Rio Grande Brazil is erecting a new chain of power stations the most important link of which is the Furnas hydroelectric station. With an ultimate output of 1,280 MVA it will be the largest power station on the whole South American Continent.

For this power station, Siemens-Schuckertwerke are supplying four 160,000-kVA, 15-kV generators with a power factor of 0.95. To suit the hydraulic conditions, generators of the umbrella type were selected with a rated speed of 150 rpm (runaway speed 282 rpm). The generator thrust bearing is designed for a total load of 1,050 tonnes; the complete generator weighs 775 tonnes.

From 1962 onwards, these four Siemens generators, which number among the largest in the world, will feed 640,000 kVA into the Brazilian power system. Together with seven other generators intended for the hydroelectric power stations at TRES MARIAS, JURU-MIRIM and BRASILIA, Siemens generators will raise the capacity of the Brazilian power system by almost 1,000,000 kVA.

* corresponding to VDE rating of 4 x 175,000 kVA




1/146 E

SIEMENS-SCHUCKERTWERKE AKTIENGESELLSCHAFT
BERLIN · ERLANGEN

# WATER POWER

*A technical journal devoted to the study of all aspects of hydro-electric development*

Annually 40 shillings by post. Single Copies 2s. 6d.

Volume 13 Number 4

**CONTENTS FOR APRIL, 1961**

Editorial: Nuclear Power for Finland? - - - 125

Editorial Notes - - - - - - 126

North of Scotland Hydro Board's Annual Report - 128

Zervreila Arch Dam - - - - - 129
*By N. J. Schnitter, Dipl. Ing. ETH., A.M.ASCE.*

Planning Expanding Electrical Systems - - - 139
*By Dr. Charles Jaeger*

The Valtellina Development—II - - - - 147

Advances in Low-Head Machines—III - - - 152
*By S. Casacci*

Design of Circular Volute Casings - - - 158
*By A. Thiruvengadam*

Short Articles: Improved Method of Cut-off Excavation —Transmission-Line-Fault Locator—Mapping Instrument—A New One-Coat Finish—400-kV Cable Tested in New Laboratory - - - - - 159

Abstracts from the World Technical Press - - 164

Editor: GRAHAM R. BAMBER, B.Sc. (Hons.), A.M.I.Mech.E.

PUBLISHED BY TOTHILL PRESS LIMITED
33 Tothill Street, Westminster, London, S.W.1
Telegrams: Trazette, Parl, London. Telephone: Whitehall 9233 (24 lines)

**MANCHESTER:** Century Insurance Building, St. Peter's Square. Telephone: Central 7667/8/9
**BIRMINGHAM:** 90 Hagley Road, Edgbaston. Telephone: Edgbaston 2466, 3728 and 3732
**NEWCASTLE UPON TYNE:** 21 Mosley Street. Telephone: 22239
**GLASGOW:** 139 Bothwell Street, Telephone: Central 4646
**LEEDS:** 70 Albion Street. Telephone: 27174
**BRISTOL:** 20 Victoria Square, Clifton Telephone: Bristol 33873

Sulzer Brothers Limited
Winterthur
Switzerland

Sulzer Bros. (London) Ltd.
31, Bedford Square,
London W. C. 1

SULZER

# Penstocks Storage Pumps

**for hydro-electric power stations**

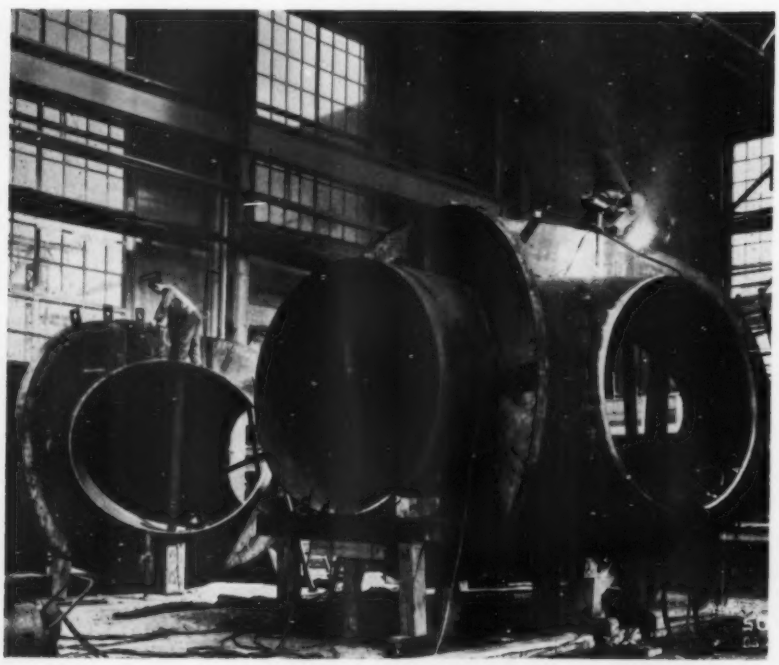
**Sulzer Brothers are supplying the following equipment for the C. E. G. B. power station at Ffestiniog, North Wales:**

**in collaboration with Messrs. Marshall & Anderson Ltd., Motherwell**

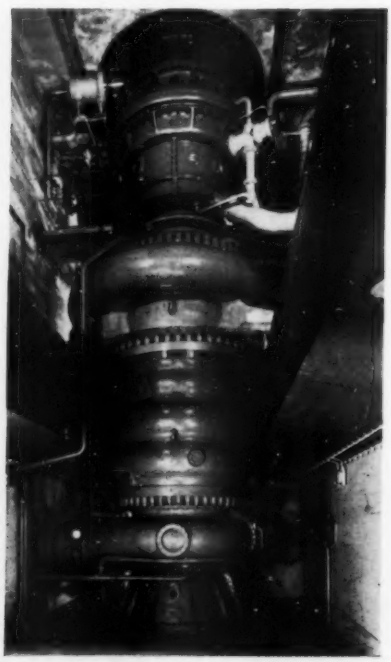
2 steel tunnel linings
4 penstocks
4 sets of branch and interconnecting pipes

**in collaboration with The English Electric Co. Ltd.**

4 high-lift storage pumps for the following working data:
Discharge 745 cu. ft. per sec.
Head 1,000 ft.
Max. input up to 110,000 H. P.



Fabrication of two branch pipes for Ffestiniog in the Sulzer shops at Winterthur. Inside diameter 7 ft. 6 in., service pressure 590 lb. per sq. in.



Sulzer five-stage high-lift pump in an Austrian power storage station. Discharge 49,250 g. p. m., head 3,186 ft., input 55,500 H. P.

SULZER

# WATER POWER

*A technical journal devoted to the study of all aspects of hydro-electric development*


# Nuclear Power for Finland?

A REPORT entitled "Prospects of Nuclear Power in Finland" has recently been published by the International Atomic Energy Agency*, and embodies the results of a joint study by the Agency and by the Finnish Atomic Energy Commission. The report is of particular interest to hydro-electric engineers because Finland has hitherto been an almost purely hydro country, but the anticipated building-out of her economic water-power resources within the next ten to fifteen years will enforce a transition to a mixed hydro and thermal system. The nature of the present power system and the characteristics of the forthcoming transition are excellently portrayed in this report, which thus has a value quite apart from the question of nuclear power with which it is basically concerned.

We gave a general picture of Finland's power economy in the Leading Editorial in our March 1960 issue, and the present report paints much the same picture, although, of course, in far greater detail. Briefly, however, Finland's present installed hydro capacity of 1,500 MW, providing a mean annual output of 7,500 GWh, represents about half of the country's economic water-power potential. By 1970 it is expected that the installed hydro capacity will be 2,400–2,570 MW, corresponding to a mean output of 12,000–12,700 GWh, and that the ultimate capacity of 14,000 GWh will be reached by about 1975. Basing estimates of future consumption on an annual rise of only 8% (for the last 15 years it has averaged 10%) the consumption in 1970 should be of the order of 19,000 GWh, leaving a shortage of about 7,000 GWh to be made good by other means.

Hitherto there has been a surplus of water power, and thermal power has been used primarily to make up deficiencies in dry years. For instance, the Imatran Voima Oy in 1958 supplied its system entirely by water power, but supplemented it with steam power in the dry year of 1959. Over the country, in a mean water year, water power has contributed 85% of the total output, condensing steam plants 5% and industrial back-pressure process-steam plants 10%. Surplus water power in times of flood has been utilised in electric boilers, which have accounted for 5–10% of the primary production.

During the next ten years, however, condensing steam power will gradually change its role from that of supplementing water power to that of providing base load, and there must therefore be a rapid increase in thermal capacity to meet this situation. At the end of 1959 the usable condensing capacity was about 370 MW (in addition there was about 200 MW of obsolescent plant) but it is considered that by 1970 a total condensing capacity of 1,400–1,620 MW should be provided. Modern back-pressure plant in 1959 totalled 398 MW, but future progress in this field is difficult to assess.

This prospective development raises a fuel problem because Finland is sadly lacking in indigenous fuels. Wood waste is naturally used to the full, but primarily by the wood-processing industry. There are extensive reserves of peat but they are unsuitable for large-scale operation on account of the small thicknesses of the deposits, their poor quality, or their remote location. In the north, too, peat cutting is practicable for only four months in the year, so that a large reserve stock would have to be carried. Thus although peat figures in future plans, its role is not expected to be large. Finland will therefore have to depend mainly on imported fuels.

Two special factors, however, may accelerate the installation of steam plants. The first is that after the most favourable water-power sites have been developed (notably on the Kemi River), hydro-electric construction will become less economic, and it is expected that by 1970 the overall hydro production costs will have risen by 15–20%. The other factor is that crushed Polish coal is obtainable at a phenomenally low price*, with the result that new condensing

* No. 2 in the Technical Report Series issued by the International Atomic Energy Agency, Kärntner Ring 11, Vienna 1, Austria.

* During the first half of 1960 the price free in power station at Helsinki was as low as 2,700 FM (£3, $8·4) per ton for coal having a calorific value of 6,000 kcal/kg (10,800 B.Th.U./lb).

units are becoming competitive with new hydro projects when transmission is taken into account.

The impact of nuclear power would be felt not on the projected hydro development but on the condensing-steam-plant programme, and the report considers the conditions under which a nuclear plant might compete with a conventional thermal plant. At present the required conditions do not exist because Finland does not yet depend on thermal plant for its base load. In 1960, for instance, thermal capacity of 100 MW was limited to a utilisation factor of 20%. By 1970, however, the utilisation factor for the thermal capacity should have risen to 80–85%, and nuclear power may then be marginally competitive. At the present moment any estimate about the comparisons in 1970 must be subject to heavy qualifications, but it is tentatively concluded that by that year a nuclear plant of 250-MW capacity may become competitive with a corresponding steam plant at a utilisation factor of 80% under conditions of low interest rate (6%) if coal prices, on a heat-cost basis, rise about 50% above their present level. By 1972–3 the energy deficiency to be met by large thermal plants will exceed 1,000 GWh per annum in four regions: Kymenlaakso, Helsinki, Turku-Forssa, and Keski-Suomi. A new 250–300 MW condensing station at Naantali is scheduled for Turku-Forssa, which will meet the deficiency in this area, so that any of the other three regions might be suitable to site a nuclear plant.

Finland's power position is not unique. In a number of other countries and provinces the gradually approaching building-out of water-power resources is bringing about a transition to a mixed system using conventional thermal or nuclear power, so that this report is of much more than local interest. It is also of interest because it bears out our oft-repeated contention that nuclear power is not competitive with water power but complementary to it.

## Power Situation in Sweden, 1959-60

THE annual report on the Swedish power situation for the year July 1, 1959, to June 30, 1960, published by CDL (Centrala Driftledningen—Central Operating Management) is interesting on two counts. On the one hand it reveals a welcome recovery from the recession of the previous year, because firm power consumption rose by 7·8% (1,940 GWh) as compared with only 3% in the preceding twelvemonth, the greatest increase being in industry at 9·1%. On the other hand, there was a prolonged drought in the summer and autumn of 1959, so that the reservoirs, which were 86% full at the beginning of the operational year, were only 70% full at the end of it, and in mid-April, 1960, they were standing at only 13·8% capacity.

Total water-power production over the period, at 26,420 GWh, was 16% less than in 1958–59, and thermal generation had to be stepped up to 17% as against 5% for a normal year. Exports and imports of power, not unnaturally, were affected. In all, 510 GWh were exported to Denmark, Finland and Norway as compared with 1,125 GWh during the previous year, and imports rose from 20 GWh to 550 GWh. Supplies to steam boilers and pumps fell from 2,395 GWh to 575 GWh.

New hydro-electric plant installed during the year raised the country's capacity by 610 MW to 6,840 MW, and the reservoir storage capacity was increased by 510 GWh to 10,600 GWh. Condensing steam plant rose by 205 MW to 1,240 MW, and back-pressure plant by 30 MW to 520 MW. Work was started during the year on 205 MW of new water-power plant.

## Turbines for Grand Rapids

A CONTRACT valued at approximately £1 million for what will probably be the world's most powerful Kaplan turbines has been awarded by the Manitoba Hydro Electric Board to the English Electric Canada division of the John Inglis Co. Ltd., Toronto. The contract is for three turbines to be installed at Grand Rapids generating station on the Saskatchewan River. Each turbine will have a rating of 170,000 h.p. at the maximum net head of 135 ft and 150,000 h.p. at the normal head of 120 ft.

The design studies for the turbines are being carried out at English Electric's Netherton Works, and model tests will be conducted at the company's hydraulic laboratories in Rugby. Manufacture will begin early next year in Toronto. Delivery of the turbines is to begin in late 1962 and the complete £50 million Grand Rapids project will go into service in 1964.

## Loan for Costa Rican Development

THE World Bank has made a loan of $8·8 million to the Instituto Costaricense de Electricidad (ICE) towards the cost of expanding the generating and transmission facilities in Costa Rica. ICE, which is an autonomous Government corporation, owns and operates 52% of the country's total installed generating capacity, as well as a central transmission network. The loan will help to finance the construction of a 30-MW hydro-electric plant on the Rio Macho, and also the installation of diesel plant and the extension of the transmission system.

The new project will be the first of a three-stage development of the Rio Macho, and the ultimate capacity of the first station is expected to be 90 MW. Connection of the station with the existing transmission system will be by means of 48 miles of new lines. The total cost of these works and additional diesel installations will be some $18·5 million, and the Rio Macho station is scheduled to be in operation in early 1963. These works are expected to enable ICE to keep pace with the increasing demand for energy, the rate of growth of which is estimated to be nearly 11% per annum over the next ten years.

## Bhakra's Second Generator Commissioned

THE second of five 90-MW generators, to be supplied by Associated Electrical Industries Limited, has been put on load, with fully automatic voltage regulation, at Bhakra hydro-electric power station. Commissioning of the remaining three machines is expected to take place at intervals of three months. The generators are rated at 100 MVA, 0·9 power factor, 166·7 r.p.m., and supply power at 11 kV, 3 ph, 50 cycles. Closed-circuit ventilation is provided, and protective relays, automatic voltage regulators, and neutral-earthing and surge-protection equipment are also being supplied.

## Canadian National Resources Conference

A CONFERENCE to consider the management of the renewable natural resources of Canada is to be held in Montreal in October. It is jointly sponsored by the Federal and the ten Provincial Governments, which will be joined by representatives of industry, voluntary associations, and the universities. The conference will not formulate recommendations for detailed action by industry or governments, but is intended to provide an opportunity to discuss, in the broadest context possible, the problems of renewable resource management and to identify problems so that broad criteria of resource management may be developed subsequent to the conference. To make the discussions as fruitful as possible, a large number of background papers will be published in advance of the conference, covering agriculture and land use, fisheries, forestry, recreation, water, wildlife and regional development. Under the heading of "water" there will be papers on various aspects of water management, on multipurpose development and on benefit-cost analysis, and several case studies of river basins will be included.

Details of the conference can be obtained from the Secretariat, "Resources for Tomorrow" Conference, c/o Department of Northern Affairs and National Resources, Ottawa.

## New Project in Pakistan

THE construction of a 1,100-ft long dam across the Jhelum River, for a multi-purpose project in West Punjab, is expected to start in the latter half of 1961. The dam will create a reservoir some 20 miles in length, and which will have a capacity of 45 million acre-ft. Six tunnels, each about 2,000 ft long, will supply a 300-MW power development, and ultimately the capacity may be increased to 1,200 MW.

## Europe's Power Supply Position in 1959-60

THE latest annual report by the Economic Commission for Europe on the present situation and prospects of Europe's electric power supply industry, shows that the period 1959–60 was, almost everywhere, characterised by a gradual but sustained acceleration of output. The consumption in Europe, including the USSR, rose by 8·5% in 1959, and in the first half of 1960 it was advancing even more rapidly. The year was marked by unfavourable hydraulic conditions over most of Europe except the extreme south-west, and, consequently, thermal plants provided most of the increased output. The total net production for 1959 was some 843,000 GWh, to which total hydro plants contributed about 252,000 GWh, or 30%.

An interesting result of the poor rainfall, coupled with the rapidly expanding industrial activity, was the swift growth of international exchanges of electrical energy. Exchanges of energy rose by about 20% to 11,700 GWh, and demonstrated the flexibility that is possible between closely connected countries. In the case of Switzerland, where there was a partial reversal of the normal seasonal pattern of net exports, imports of energy from five countries rose to more than a fifth of the total requirements over a period of five months from October 1959.

The report notes that, in the five years from January 1, 1960, a number of very large hydro schemes are due for completion. The total new capacity of all types of plant is likely to exceed 50% of that now in service in several countries, and, in general, there appears to be a marked emphasis on different types of plant for peak-load use. Under existing conditions, some reappraisal of unused hydro-electric resources is being made, and the limit of the total economically utilisable resources is being extended in many cases. Of the countries planning to make large increases in their hydro capacity, Switzerland, Sweden, Spain, Greece and Luxembourg will all make very substantial inroads on their economic potential. By the end of 1964, Switzerland will have exploited some 77% of her hydro potential, thus making her the most highly developed of Europe's hydro-power countries.

## Russian Aid for Bui Project

PART of the £14½ million loan from the USSR to Ghana, which was announced last year, will be used to assist the financing of the Bui project on the Black Volta. It is reported that a station of 200-MW capacity is to be installed, and the Soviet Government has undertaken to supply all the necessary equipment and materials.

In 1956, the Volta River Project Preparatory Commission recommended an initial installation of 120 MW in an underground power station at Bui. The firm output of the proposed station was estimated to be some 65 MW continuous, and the ultimate installed capacity was to have been 160 MW. The dam proposed at that time was of the buttress type, and the other major feature of the scheme was a 140-mile long transmission line to Kumasi, which lies to the south of Bui.

## Yugoslav Power Loan

THE World Bank has approved a loan to Yugoslavia equivalent to $30 million to help to finance the construction of a 216-MW hydro-electric plant in the Velebit Mountains near Senj on the Adriatic Coast, and the installation of 790 miles of high-voltage transmission lines. The projects are part of a programme being carried out by Yugoslavia to double electric generating capacity in the next five years.

The Senj plant will utilise the waters of the Gacka and Lika Rivers in the Velebit Mountains. A concrete arch dam will be built on the Lika River to create a storage reservoir; other structures include three diversion dams, 20 miles of tunnels and an underground power house containing three 72 MW units. The new transmission lines will extend throughout five of Yugoslavia's six Republics — Serbia, Slovenia, Croatia, Bosnia-Herzegovina and Montenegro. The total cost of the Senj power plant and new transmission network is estimated at the equivalent of $75 million. The Bank loan will provide 40% of the required financing. Imported equipment needed for the projects will be purchased on the basis of international competition.

Yugoslavia's high mountains and heavy rainfall have endowed it with abundant water-power resources, of which less than a tenth has yet been developed. Its resources are as great as those of Italy

and, in Western Europe are substantially exceeded only by those of Norway. Most of Yugoslavia's hydro-electric installations are run-of-river plants which must be supplemented by reservoir and thermal plants. During the next few years consumption is expected to grow at the rate of 15% annually and in the present power-expansion programme new hydro-electric and thermal plants will be built to double the present capacity of 1,950 MW by 1965; nearly 1,100 miles of transmission lines, of which 790 miles will be 220 kV, together with associated transformer and switching stations, will be constructed.

### British Electrical Power Convention

THE annual British Electrical Power Convention is to be held at Eastbourne from June 12-15, 1961. Of special interest in the hydro-electric field will be a paper, "The Electrical Power Industry in Canada," by Dr. A. E. Grauer, Chairman of the British Columbia Electric Co. Ltd. Other papers will include "The British Electricity Transmission System" by Sir Christopher Hinton, Chairman of the Central Electricity Generating Board, "Some Aspects of Efficiency and Economy in Distribution" by Mr. R. R. B. Brown, Chairman of the Southern Electricity Board, and "British Electrical Manufacture in the National Economy" by Mr. S. F. Steward, Director of the British Electrical and Allied Manufacturers' Association.

### Further Canadian Assistance for Kundah

FOLLOWING the completion of the second stage of the Kundah project in Madras, the Canadian Government has now agreed to participate in the final stage of this development by providing equipment and services valued at about Rs. 90,000,000.

Power station No. 2, which at present has an installed capacity of 70 MW, was recently inaugurated, and the first station of 40-MW capacity came into operation in March, 1960. The ultimate installed capacity of the whole scheme will be 420 MW, and a firm output of 343 MW is anticipated. The first two stages of the project cost some Rs. 354,400,000, towards which Canada contributed about one-third under the Colombo Plan, and it is estimated that the third stage will cost a further Rs. 230,600,000.

## North of Scotland Hydro Board's Annual Report

The annual report for 1960 of the North of Scotland Hydro-Electric Board shows that the year was remarkable for the poor rainfall in the Board's area at a time when most of the rest of Great Britain was receiving rainfall that was up to 160% of average. The mean rainfall over the Board's catchments was 86% of the long-term-average value, and this resulted in the river flows being reduced to 81% of average.

Despite this setback the Board's hydro stations were able to increase their output over the year, although this increase naturally resulted in a decline in the volume of water stored in the reservoirs. At the end of 1960, the water stored, expressed as a percentage of the total available capacity, was 55·6%, and showed promising signs of recovery. The retention of even this proportion, which was essential in order to meet the heavy winter loads, necessitated increased generation by the Board's thermal stations, particularly in the second half of the year, and the importation of some 96 million units from the South of Scotland Electricity Board. This figure compares with the 565·3 million units that were exported by the Board.

Although the total output of all stations increased by some 239 million kWh over the 1959 total of 2,196 million kWh, the estimated loss of output due to the poor rainfall was 456 million units. As a result the Board were able to show only a modest profit on their sales of electricity. The generating cost of hydro power was 0·7874d. per unit, which compares with the generating cost from all sources of 0·8374d. per unit.

No large additions to the installed capacity of the Board's stations were made in 1960. The Shin scheme was completed by the commissioning of the second set, of 7·5-MW capacity, at the Cassley station, and this brought the total installed capacity up to some 875 MW. In addition the schemes at present under construction will add another 572 MW. Of the new works by far the largest contributor will be the Cruachan pumped-storage installation, which forms part of the Awe scheme (described briefly in the February 1961 issue of WATER POWER). Contracts to the value of some £1½ million were placed during the year for works at Loch Awe, and the report states that the main contracts for the Cruachan section were expected to be let early in 1961. Work on the Inverawe power station and barrage has made good progress.

Approximately ten miles of tunnels, mostly on the Strathfarrar works, were driven during the year, and the rockfill dam at Lochan Breaclaich, which is in the St. Fillans section of the Breadalbane scheme and is of similar design to that at Quoich, was completed. The main 132-kV transmission system was extended by 101 miles, and the first 12-mile section of the new 275-kV system was energised initially at 132 kV.

During the year the Nevis project was promoted, and in this scheme it is proposed to use the waters of the River Nevis to develop power at a 25-MW underground station at Loch Leven. A scheme to provide greater regulation for the Tummel stations by raising the level of Loch Laidon is also being prepared. These and other projects now under investigation have a potential total capacity of 555 MW.

The Board has been carrying out its own researches in a number of different fields, including the study of improved devices for counting and checking fish movements in fish passes. Experiments have been carried out on a possible means of combating cavitation on turbine runners, in which erosion-resistant coatings of synthetic rubber have been applied to the blades. Further computer studies have been made, and a variety of tests on installed generators carried out. A good deal of work relating to transmission problems was done, including the development, in conjunction with Ferranti Limited, of a fault locator using high-frequency pulse techniques.

An interesting feature of the Board's work in 1960 was the inspection of all their major dams. Under the terms of the Reservoirs (Safety Provisions) Act of 1930, ten-yearly inspections are obligatory in the United Kingdom, but in view of the Fréjus disaster in France, the Board arranged for special inspections, all of which resulted in favourable reports.

*Fig. 1. Zervreila dam in winter, looking upstream towards Zervreila peak*

# Zervreila Arch Dam

Some details are given of the design and construction of this important Swiss dam, which impounds the main storage for a 206-MW three-station scheme in the Grisons

By N. J. SCHNITTER, Dipl.Ing.ETH., A.M.ASCE.,
Design Engineer, Motor-Columbus Limited, Baden, Switzerland

ZERVREILA dam, almost 500 ft (150 m) high and completed in 1957, is a fair representative of present-day Swiss large arch-dam engineering practice. Of the 14 dams of more than 330 ft (100 m) height built in Switzerland since World War II, or at present under construction, eight, or 57%, are of the same type as Zervreila, which ranks among them fifth in height and fourth in concrete volume.

Zervreila dam impounds the 81,000 acre-ft (100 million $m^3$) main storage reservoir of the three-station power scheme. The project is located in the state of Grisons and develops the potential of the Valserrhein and Rabiusa Rivers, two southerly affluents to the Vorderrhein. The latter constitutes one of the two forks of the Rhine in its uppermost reaches. The power scheme extends over three valleys (Fig. 2) and has a total installed capacity of 206 MW. Its average yearly power production, after deduction of pumping energy, is estimated at 455 million kWh. Kraftwerke Zervreila Limited, the company formed to build and operate the development, is a joint venture by the two public utilities Sernf-Niederenbach Limited and Nordostschweizerische Kraftwerke Limited and the privately owned financing company Motor-Columbus Limited. The technical departments of the latter have also been responsible for the design and the supervision during construction of Zervreila dam and other pertinent parts of the scheme.

The dam site presented itself quite naturally just where the Valserrhein leaves the relatively wide and flat Zervreila valley to enter a steep and narrow gorge. After comparative studies it was decided to place the dam at the very beginning of the canyon. The valley profile there is V-shaped, with a steep left and a flatter right flank. The latter is covered by an overburden of some importance. On both sides the rock is crystal-

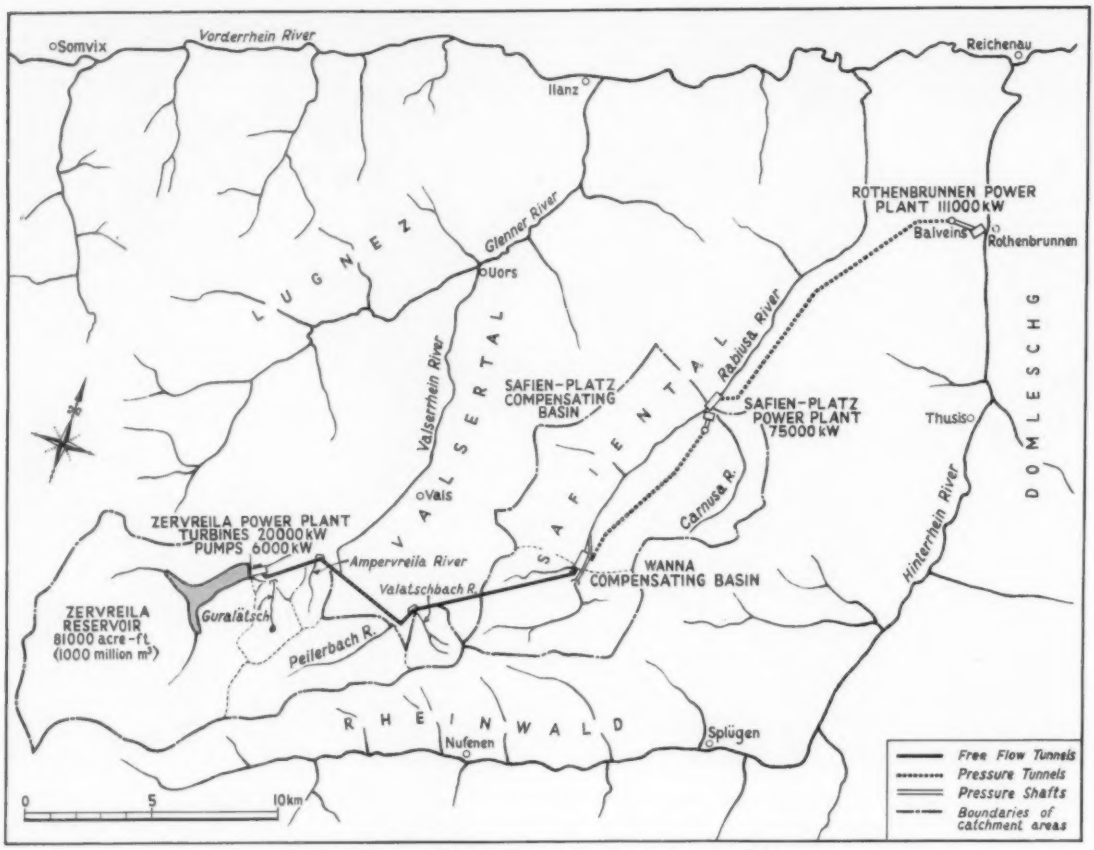



*Fig. 2. Map of Zervreila three-plant power scheme*

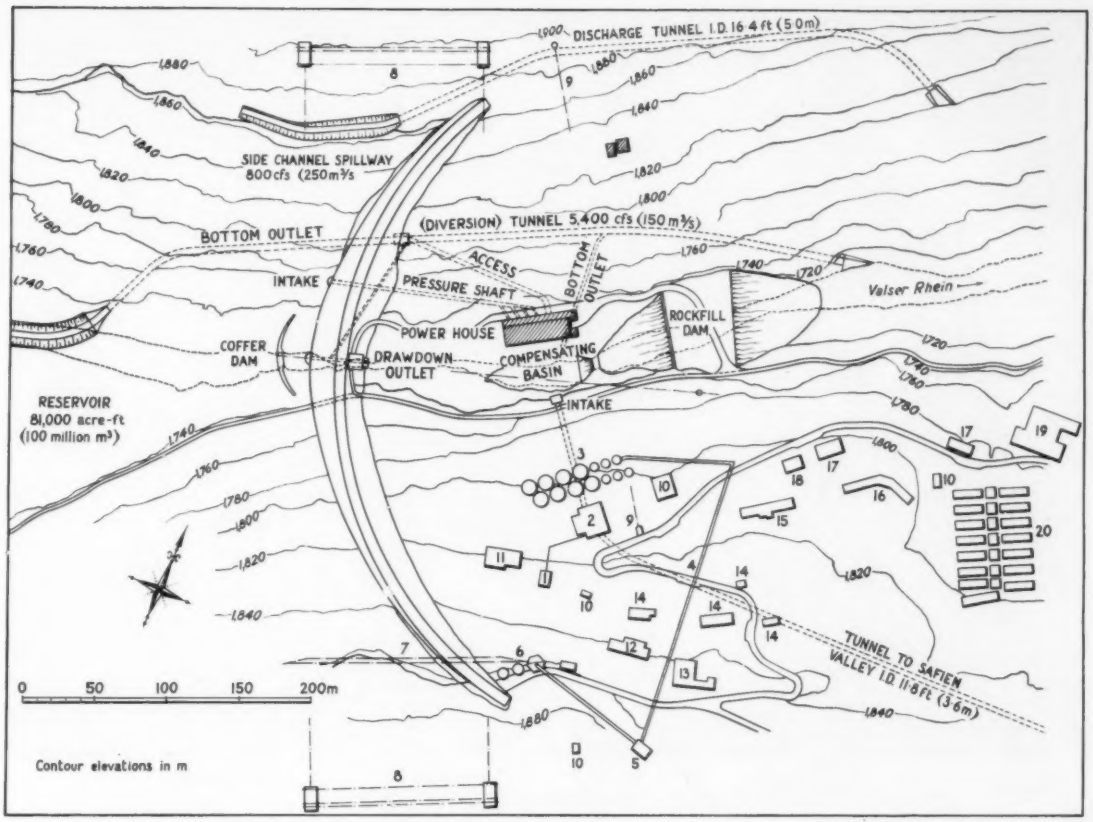
line gneiss with the strata dipping about 20° from the right to the left wall. This condition and the abundant crevasses, which generally strike along and across the river and dip almost vertically, entail a superficial loosening of the rock on the right flank, but the strata are perfectly sound and compact on the left flank. The preliminary geological investigations were, therefore, concentrated almost entirely on the right side of the valley. They comprised several borings and five exploration galleries. Among these, one was driven to 913 ft (279 m) in order to verify conclusively the integrity of the right flank as a whole and to disprove certain fears as to the existence of ancient slip planes, which a gully beyond the right abutment of the dam (Fig. 3) seemed to indicate. The careful exploration work, moreover, permitted a very close advance determination of the depth of the foundation excavation. As a check, both valley sides were also explored by the geoseismic method, which furthermore gave an indication for the mean elastic modulus of the rock mass to be introduced into the static analysis of the dam.

TABLE I.—PRINCIPAL DIMENSIONS AND QUANTITIES

| | |
|---|---|
| Crest elevation above sea level | 6,110 ft (1,863·5 m) |
| Maximum height above foundation | 494 ft (150·5 m) |
| Crest length | 1,653 ft (504·0 m) |
| Crest width | 23 ft (7·0 m) |
| Base width | 115 ft (35·0 m) |
| Upstream radius of crest arch | 835 ft (255·0 m) |
| Central angle of crest arch | 113° |
| Excavation volume: | |
| Overburden | 29,700 cu yards (22,700 m³) |
| Rock | 207.400 cu yards (158.600 m³) |
| Concrete volume | 818,300 cu yards (625,600 m³) |

## Geometry of the Dam

The V-shape of the dam site and its ratio of width to height of 2·7 were favourable for construction of an arch dam, the principal dimensions of which are summarised in Table I. The type selected was that of a constant-angle variable-centre or Jorgensen arch dam, which yields optimum static conditions with a minimum of concrete volume. With large structures like the present one, the complications entailed by this type of construction, e.g., in respect to the often overestimated formwork, are of no importance. The vertical section in the plane of the arch centres (Fig. 4) was laid out so as to reconcile the necessary overhangs with adequate stability of the independent construction blocks, without having to resort to stabilising artifices, which might have resulted in undesirable restrictions upon the construction schedule (subsequently shortened an entire year by the contractor). The arches are circular and of constant thickness, with identical downstream fillets at both abutments in the lower two-thirds of the dam. The arch centres are arranged on a smooth curve to obtain at each elevation




1=primary crusher, 2=aggregate processing plant, 3=aggregate storage bins, 4=belt conveyor, 5=secondary screens, 6=concrete batching plant and cement silos, 7=bucket loading platform, 8=cableways, 9=auxiliary cableway, 10=transformer stations, 11=carpenters' shop, 12=compressor station, 13=machine shop, 14=stores, 15 and 16=offices and contractor's quarters, 17 and 18=offices and supervisors' quarters, 19=canteen, 20=workers' quarters.

*Fig. 3. Plan of dam site and construction camp and equipment*

the maximum aperture and curvature compatible with adequate transmission of the arch thrusts into the canyon walls. This condition was considered to be satisfied if a line drawn in a downstream direction from the junction of the downstream face with the abutment, at an angle of 30° to the tangent to the face at the junction point, remained within the rock cover at that level. The face of the abutment is radial over the downstream half, and is inclined 10° outwards from a line parallel to the plane of the arch centres over the upstream half. The geometry of the abutment is indicated in Fig. 8. The only exception to the 30° rule is at the crest of the dam. Moreover, on the right flank, which is characterised by the superficial loosening already mentioned, the excavation had to be carried to a minimum depth of about 30 ft (10 m) in any case to secure a firm abutment. Finally, the excavation line was smoothed out in a longitudinal direction as much as economically feasible.

**Static Analysis**

For all preliminary designs and for the development of the final dimensions of the dam, extensive use was made of the simple and convenient analysis by crown adjustment, i.e., by distributing the external loads upon a single vertical section—usually the prin-

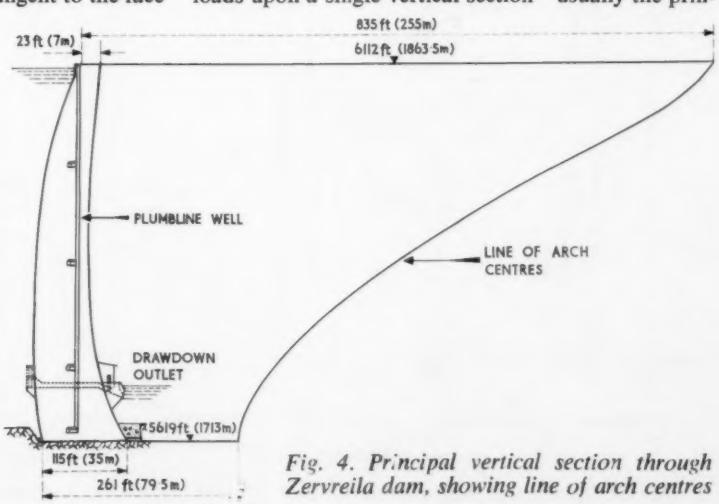



*Fig. 4. Principal vertical section through Zervreila dam, showing line of arch centres*

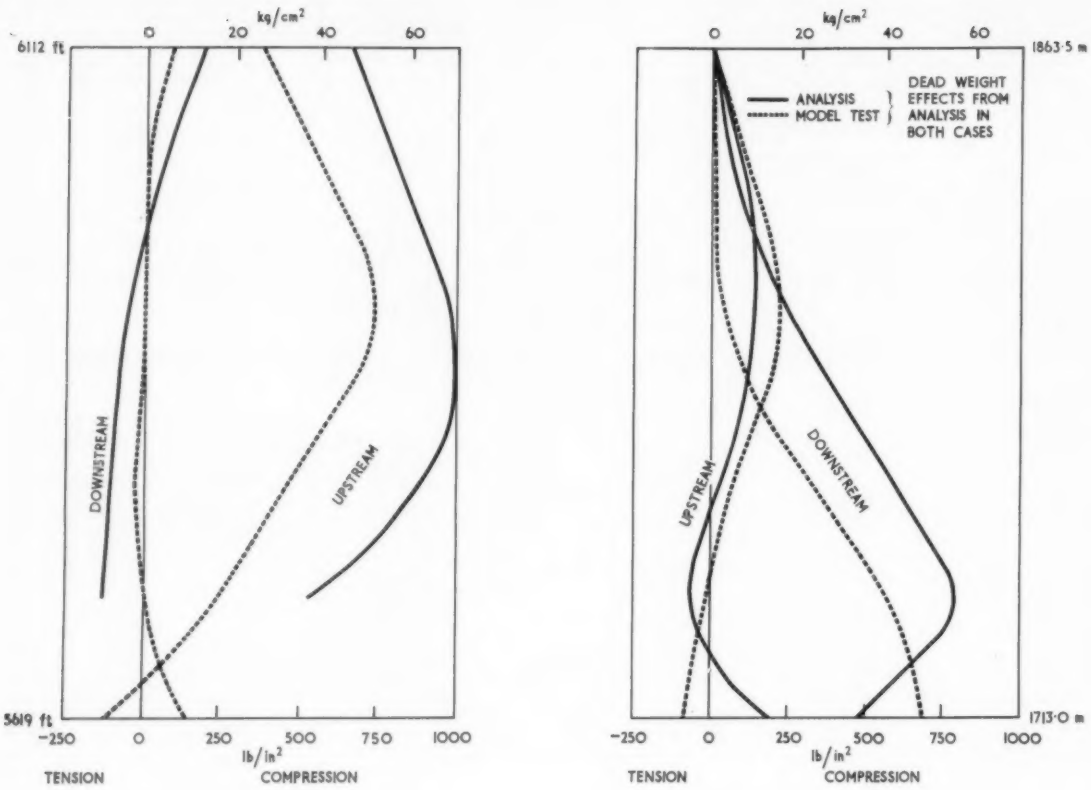



*Fig. 5. Comparison of horizontal and vertical normal stresses due to water load and dead weight from analysis and model test*

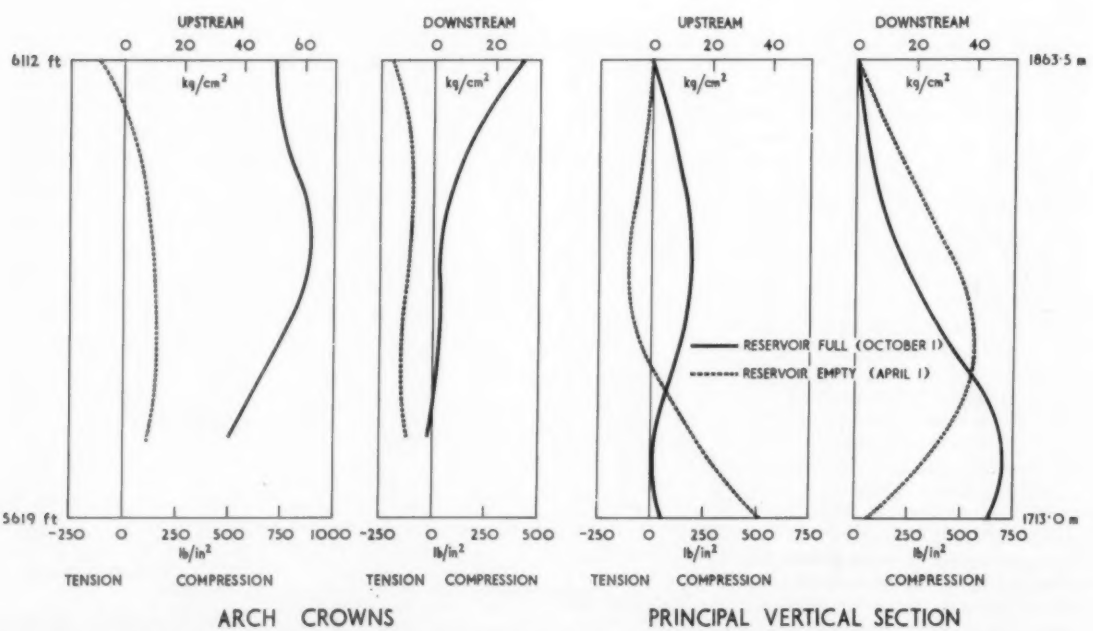



*Fig. 6. Horizontal and vertical normal stresses from two analyses including the thermal effects*

*Fig. 7. The dam in course of construction*

cipal one—and a number of arches in such a way that their radial deflections coincide. With the help of appropriate graphs for the arch stresses and crown deflections, this type of computation takes but a few man-days to complete. It is still the biggest single step forward in a process of approximation in which each successive stage earns less for an ever-increasing amount of calculation. Much of the latter has nowadays been transferred to electronic computers, which were not generally available at the time Zervreila dam was designed. Further refinements introduced into the static analysis of the final design, therefore, were restricted to taking into consideration the downstream fillets at the arch abutments and two, finally six, additional vertical sections for the radial-deflection adjustments. As a check on the quality of this analysis and the influence of the neglected shear and twist effects, at least for maximum water load, a model test at a scale of 1 : 250 was carried out. The model was cast in the plastic "P 1200" mixed with cork and loaded by means of hydraulic jacks. Stress determination was made on both faces with strain gauges. A comparison of the results obtained on the model with those from the analysis is given in Fig. 5. In both cases the ratio of the elastic moduli of rock and concrete was taken as unity throughout, in accordance with the average results from the seismic exploration of the dam site.

Considerable effort was devoted to a realistic appraisal of thermal effects, which play an as yet imperfectly understood and often underestimated part in dam behaviour, and may render futile over-refined searches for the ideal dam shape. The approach used in the present case was to assume the exterior temperatures on both faces to oscillate in phase and according to laws of the type:

$$\theta_I = \theta_{MI} + \theta_{OI} \cos \frac{2\pi t}{T}$$

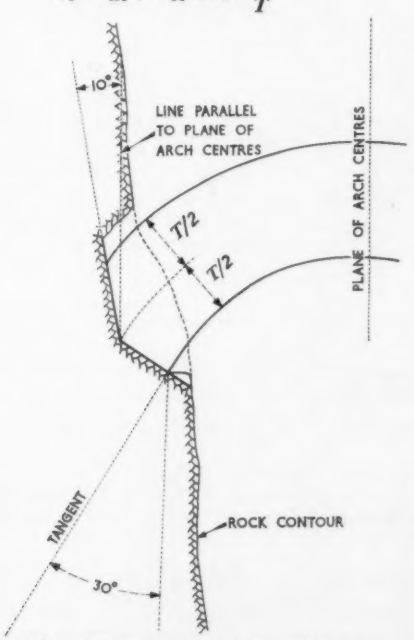



*Fig. 8. Geometry of the abutment*

TABLE II.—INFLUENCE OF SAND COMPOSITION ON PROPERTIES OF EXTERIOR CONCRETE
(Laboratory test results)

| Sand composition | 0·1–0·8 mm / 0·8–2·4 mm | 6/4 | 5/5 | 4/6 |
|---|---|---|---|---|
| Water/cement ratio | | 0·57 | 0·56 | 0·52 |
| Compr. strength on 8 in (20 cm) cubes at 28 days age in lb/in² (kg/cm²) | | 3,980 (280) | 4,320 (304) | 4,670 (328) |
| Min. leaking pressure of 8 in (20 cm) cubes in lb/in² (kg/cm²) | | 60 (4) | 110 (8) | 170 (12) |
| Deficit of elastic modulus after freezing and thawing in % | 50 cycles | 7 | 10 | 12 |
| | 100 cycles | 11 | 10 | 9 |
| | 500 cycles | 5 | 10 | 10 |

NOTE: 422 lb/yd³ (250 kg/m³) cement content, 1·9 in (48 mm) maximum aggregate size and 3·7% entrained air throughout. Mixing water adapted to equal consistency and referred to bone-dry aggregates. Deficit of elastic modulus related to water-cured companion specimens and corrected for differences in starting values.

The uniform temperature and the temperature gradient, which are equivalent to the actual temperature distribution across the section and which have to be introduced into the analysis, will then change with time as follows:

$$\theta=\frac{\theta_{MU}+\theta_{MD}}{2}+\frac{\theta_{OU}+\theta_{OD}}{2}\left(A\ \cos\frac{2\pi t}{T}+B\ \sin\frac{2\pi t}{T}\right)-\theta_G$$

$$\Delta\theta=\theta_{MU}-\theta_{MD}+(\theta_{OU}-\theta_{OD})\left(C\ \cos\frac{2\pi t}{T}+D\ \sin\frac{2\pi t}{T}\right)$$

where $\theta_I$ = exterior temperature ($I$ stands for index $U$ or $D$).
$\theta_{MI}$ = mean exterior temperature over period.
$\theta_{OI}$ = maximum oscillation of exterior temperature.
$t$ = time.
$T$ = period of oscillation.
$\theta$ = uniform temperature across section.
$\Delta\theta$ = temperature gradient (positive from upstream to downstream face).
$U$ = index indicating upstream face.
$D$ = index indicating downstream face.
$\theta_G$ = mean temperature across section at time of grouting contraction joints.

$$k=\sqrt{\frac{\pi}{\delta T}}$$

$d$ = thickness of section.
$\delta$ = diffusivity.

The maxima and minima of the above expressions, which do not occur simultaneously, are:

$$\theta_m=\frac{\theta_{MU}+\theta_{MD}}{2}\pm\frac{\theta_{OU}+\theta_{OD}}{2}\ \sqrt{A^2+B^2}-\theta_G$$

$$\Delta\theta_m=\theta_{MU}-\theta_{MD}\pm(\theta_{OU}-\theta_{OD})\ \sqrt{C^2+D^2}$$

The hyperbolic functions $A$, $B$, $C$ and $D$ may be simplified for thicknesses of more than about $4/k$ to read*:

$$A=B=\frac{1}{kd}\quad\sqrt{A^2+B^2}=\frac{\sqrt{2}}{kd}$$

$$C=\frac{3}{kd}\quad D=\frac{3}{kd}\left(1-\frac{2}{kd}\right)$$

$$\sqrt{C^2+D^2}=\frac{3}{kd}\sqrt{1+\left(1-\frac{2}{kd}\right)^2}$$

For Zervreila dam the temperature at the downstream face was assumed to oscillate a maximum of 22·5°F (12·5°C) around a yearly mean of +36°F. (+2°C). On the upstream face the oscillation was gradually reduced to zero and the mean raised to +39°F (+4°C) from the crest of the dam to its base. The diffusivity of the concrete was established experimentally at 0·043 ft²/$h$ (0·004 m²/$h$). Fig. 6 shows, in analogy to Fig. 5, the results of a stress analysis including the thermal effects and taking into account all their influences on the radial deflections of the dam.

**Concrete Technology and Temperature Control**

Short of opening a quarry and accepting an overall construction-cost rise of about 15%, the only source of aggregates available within reasonable distance were the fluvial deposits in Zervreila valley proper, about one mile (1·6 km) upstream from the dam site. The quality of these aggregates, consisting mostly of gneiss with considerable amounts of mica and deteriorated particles, was known not to be first class. Fortunately, the latter was true in respect to the strength characteristics of the concrete only, whereas its other, by no means less important properties, like durability, watertightness, and extensibility, were excellent. Apart from ease of access and of exploitation, the selected site presented also the advantage of not encroaching permanently upon the landscape, as the pit would subsequently be submerged by the reservoir. On the other hand, since a partial filling of the latter before completion of construction was envisaged, a considerable stock of aggregate had to be accumulated.

In order to develop the strength of the aggregate as much as possible, the minus 0·1 in (2·4 mm) sand was separated by means of closely controlled RHEAX classifiers into three fractions, of which the finest, i.e., all grain sizes below 0·04 in (0·1 mm), was completely

* For the exact expressions see: Int. Assoc. for Bridge and Structural Engineering Publications, 7th Volume (Zürich, 1943/44), pages 293-309 (Prof. M. Ritter).

TABLE III.—STRENGTH CHARACTERISTICS OF CONCRETE

| Cement content | Water/ cement ratio | Age of specimens | Coefficient of variation | Compressive strength | |
|---|---|---|---|---|---|
| | | | | 8 in. (20 cm) cubes | 6 × 12 in cylinders |
| lb/yd³ (kg/m³) | | days | % | lb/in² (kg/cm²) | |
| 337 (200) | 0·69 | 7 | 16·6 | 2,100 (148) | 1,150 |
| | | 28 | 16·3 | 3,090 (217) | 2,020 |
| | | 90 | 15·9 | 3,840 (270) | 2,690 |
| 422 (250) | 0·58 | 7 | 16·7 | 2,870 (202) | 1,830 |
| | | 28 | 12·5 | 3,950 (278) | 2,790 |
| | | 90 | 14·4 | 4,690 (330) | 3,450 |
| 472 (280) | 0·56 | 7 | 15·0 | 3,190 (224) | 2,110 |
| | | 28 | 13·1 | 4,270 (300) | 3,070 |
| | | 90 | 13·1 | 4,940 (347) | 3,670 |

NOTE: Water/cement ratio referred to bone-dry aggregates. Concrete wet screened to 1·9 in (48 mm) maximum grain size. Specimens cured in water at 64°F (18°C). Strength of cylinders computed from that of cubes.

discarded. Comparative tests established the gain in concrete strength obtainable by such dedusting to be close upon 20%. The operation furthermore helped to lower the moisture content of the remaining two sand classes and to reduce its variations, and hence those of the concrete strength. Through tests of the type summarised in Table II the most desirable recomposition of the two sand fractions was also studied. In actual practice, variation within the investigated border cases was permitted. But notwithstanding these special precautions, the relatively high minimum cement content of 337 lb/yd³ (200 kg/m³) had to be used in order to obtain concrete strengths assuring a sufficient and reasonable safety margin over the maximum stresses resulting from the static analysis. Along the foundations and within 5 to 6 ft (1·5 to 1·8 m) thick zones on the downstream and upstream faces, the cement content was raised to 422 and 472 lb/yd³ (250 and 280 kg/m³) respectively to render the concrete either more durable or more impermeable. The cement was ordinary Portland, and a purely air-entraining agent FRO-BE (Sika Corp.) was added to all mixes. The aggregate gradations are represented, in terms of their actual limits of variation, in Fig. 9 which also gives the grain-size ranges of the aggregate classes employed. The average water/cement ratios used are given in Table III.

The same table presents the average compressive strengths achieved at various concrete ages and the respective coefficients of variation (standard deviation divided by average). The modulus of elasticity at 90 days of age averaged from 1,960,000 to 2,260,000 lb/in² (138,000 to 159,000 kg/cm²) depending on the mix. Notwithstanding, or possibly because of such low values, the concrete exhibited excellent frost resistance. After 1,000 cycles of alternative freezing in air to −13°F (−25°C) and thawing in water to +59°F (+15°C) the 8 by 8 by 24 in (20 by 20 by 60 cm) specimens of both exterior concretes showed an average deficit in the elastic modulus of 8% and in the compressive strength of 5% as compared with water-cured companion specimens. Remarkable was also the watertightness of the upstream exterior concrete, in that only 10% of the 8 in (20 cm) cubes tested presented any leakage up to the maximum water pressure acting on the dam, i.e. about 200 lb/in² (15 atm.). As usual, the laboratory test-results

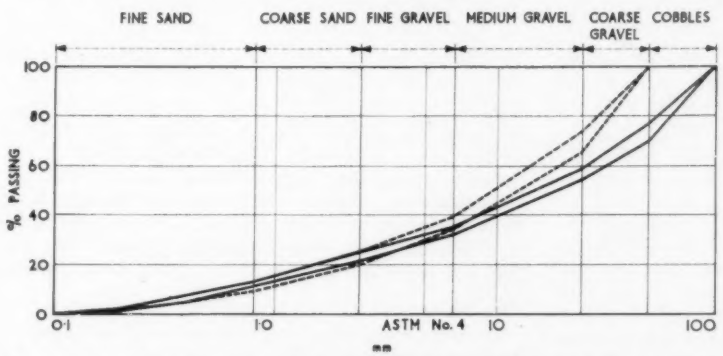



*Fig. 9. Actual aggregate grading of Zervreila arch-dam concretes, with ranges of fractions produced by processing plant. Maximum size was 3·8 in (96 mm) for interior and downstream exterior and 1·9 in (48 mm) for upstream exterior concrete. All grain sizes given are referred to square-mesh sieve sizes*

TABLE IV.—CONCRETE PLACEMENT

| Year | Month | In % of volume | In % of plant capacity | In % of placement possibility |
|---|---|---|---|---|
| 1955 | May | 0·2 | — | — |
| | June | 2·0 | 12 | 50 |
| | July | 4·4 | 27 | 66 |
| | August | 6·9 | 43 | 75 |
| | September | 10·0 | 62 | 87 |
| | October | 7·3 | 45 | 55 |
| | November | 5·8 | — | — |
| 1956 | April | 0·4 | — | — |
| | May | 8·7 | 54 | 59 |
| | June | 15·5 | 96 | 97 |
| | July | 14·7 | 91 | 82 |
| | August | 15·1 | 93 | 87 |
| | September | 8·5 | 53 | 64 |
| | October | 0·5 | — | — |

NOTE: Theoretical plant capacity 260 yd³/h (200 m³/h). Placement possibility based on monthly average of available surface and 72 hours net waiting time between the 10 ft (3 m) lifts. Fifty 10-hour shifts assumed for all months.

were checked on cores drilled from the dam. Among a total of 130 ft (40 m) of such cores only one small gravel pocket was found.

In spite of the relatively low ambient temperatures, the considerable concrete thicknesses necessitated the provision of means for an accelerated removal of the heat of hydration in order to permit the closure of the contraction joints, and hence the filling of the reservoir at the earliest date possible. One of the two methods contemplated for this heat removal was the classical widening of the contraction joints into cooling slots, which in the lower half of the dam, however, could not have been backfilled—in itself a complicated operation—until the second spring after concrete placement. The other cooling system taken into consideration, and finally adopted, was that of circulating cold water through pipes embedded in the concrete at each construction lift. Although it had been in use in the United States for many years, the method was only then being introduced into Swiss dam engineering. Today it is the standard procedure for all dams with concrete more than about 30 ft (10 m) thick. In comparison with the usual American practice the applications in Switzerland have the advantage that ordinary river water is generally available in sufficient quantities, at low-enough temperatures, and under a natural head. Notwithstanding the additional cost of 45 miles (73 km) of pipes and an intricate water-distribution system, the artificial cooling by embedded pipes afforded a saving in overall construction expenditure of 5% as compared with the method involving cooling slots, to which may be added an equal amount gained in electric power production owing to earlier filling of the reservoir.

**Construction**

After certain preparatory works, such as the construction of the diversion tunnel and widening and relocating the access road, construction on the dam proper began at the end of August 1953. The contract, based on lump-sum payments towards the construction plant and equipment and on unit prices for all works, was allocated to a joint venture of several Swiss contractors sponsored by H. Hatt-Haller Ltd., of Zürich*. The first eighteen months of the construction period were devoted to the foundation excavation (see Table I for the quantities) and to the erection of the camp and the construction plant (Fig. 3). The main items of equipment installed were: an aggregate processing plant with an output of 275 yd³/h (210 m³/h) and stock bins totalling 13,000 yd³ (10,000 m³); an automatic batching tower equipped with four tilting mixers each of 4 yd³ (3 m³) capacity; and two parallel travelling overhead cableways spanning 1,600 ft (500 m) and each of 20 tons capacity.

The total capacity of all machines on the job amounted to 10,000 h.p., which was divided about equally among the electric and the diesel motors. Between completion of the excavation and beginning of the concrete placement a grout curtain was put down to a depth of 260 ft (80 m) below the foundation. In this operation the differences in the compactness of the rock strata on both flanks showed up very strikingly, as the average cement intake on the right side was over 15 times higher than that on the left. The overall average amounted to 270 lb/ft of borehole (400 kg/m) or 20 lb/ft² of grout curtain surface (95 kg/m²). The contact grouting, done after concrete placement had reached a certain height, followed the same pattern, with an overall average cement intake of 11 lb/ft² of foundation area (50 kg/m²).

Concrete placement was started on May 16, 1955, and completed by October 6 of the following year. The concrete volumes poured each month are summarised and analysed in Table IV, which illustrates some typical peculiarities of arch-dam construction in the Alps. The most important of these is the seasonal character of construction due to climatic conditions. At Zervreila only the four months from June to September permitted full activity, hindrance by frost, fog, and snow increasing progressively before and after the indicated period. The situation was

TABLE V.—CONSTRUCTION COST BREAKDOWN
(except appurtenant structures and overhead cost)

| | |
|---|---|
| Preliminary exploration ... ... ... ... | 1% |
| Construction plant and equipment .. ... ... | 29% |
| Excavation ... ... ... ... ... ... | 6% |
| Foundation grouting ... ... ... ... ... | 3% |
| Concrete (except cement) ... ... ... ... | 30% |
| Cement ... ... ... ... ... ... ... | 30% |
| Concrete testing and instruments in dam ... ... | 1% |

* The other participants were: Schafir & Mugglin Limited, Zürich; Rätus Limited, Coire; Prader & Company, Coire; Sigrist-Merz & Grüebler Limited, St. Gallen; and Toscatti & Company, Bilten.

*Fig. 10. Commencement of concrete placement in the dam foundation*

aggravated by the fact that in the lower parts of dams with a V-shaped longitudinal profile, especially arch dams, the horizontal surface available at any time for placing the lifts at given intervals is restricted. This explains why the design capacity of the construction plant could be utilised fully for only three months in 1956, or just 18% of the time theoretically employed for concrete placement. During these three months, however, 45% of the total concrete volume were poured, with a peak output of 6,800 $yd^3$ (5,200 $m^3$) within two 10-hour shifts. At the same time the labour force reached its highest level of 500 men.

Concrete placement proceeded in blocks of about 40 to 60 ft (12 to 18 m) length between the contraction joints, which, by the way, were plane. Each lift was built up in six layers of 20 in (50 cm) thickness, which were required to be covered by the next layer within two hours. After discharge from the 8 $yd^3$ (6 $m^3$) bucket the concrete was spread out by a D 4 bulldozer and compacted with high-frequency needle vibrators operated by two men. On more recent projects this operation has been mechanised by attaching the vibrators in batteries of three to four instruments to the front of tractors. Incidentally, the fact that these travel easily gives a good measure of the consistency usually achieved in Switzerland for the concrete in a dam. After completion of the pour each lift surface was cleaned with pressurised water and air, the treatment being repeated after the prescribed waiting period and before the spreading of a thin layer of mortar and the resumption of operations. In the following spring the contraction joints were closed by the injection of grout through a system of embedded pipes and valves. The average cement used amounted to 2·7 $lb/ft^2$ of joint surface (13 $kg/m^2$).

The total construction costs of the dam, excepting appurtenant structures and overheads, reached US $10 million or about $13/$yd^3$ of concrete volume ($17/$m^3$). A breakdown of costs is given in Table V.

**Structural Behaviour**

The instruments embedded in the dam are restricted to the measurement of deflections and temperatures, but comprise three plumblines and 215 resistance thermometers. As a check on the plumblines two geodetic precision surveys have been run each year since the completion of construction. Owing to the relatively low values of the elastic moduli of the concrete as well as of the rock, the movements of the dam are considerable. At the crown of the crest, for instance, the deflection oscillates as much as 4·1 in (10·5 cm) from full to empty reservoir between autumn and spring. By means of two geodetic measurements at the same reservoir level within two years it has been possible, short of the inexplicable but slight differences in the thermal state of the dam, to determine the permanent deformations that occurred during the period. From Fig. 11 the radial, tangential and vertical components of these permanent deflections can be seen, and the marked difference in the behaviour of the two valley sides is again visible. While the sound left flank reacted more or less elastically, the loosened right abutment

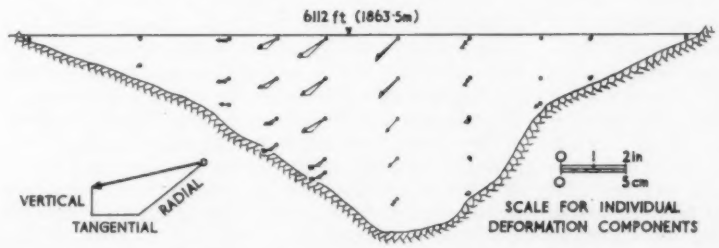



*Fig. 11. Permanent deformations in the dam from October 1957 to October 1959*

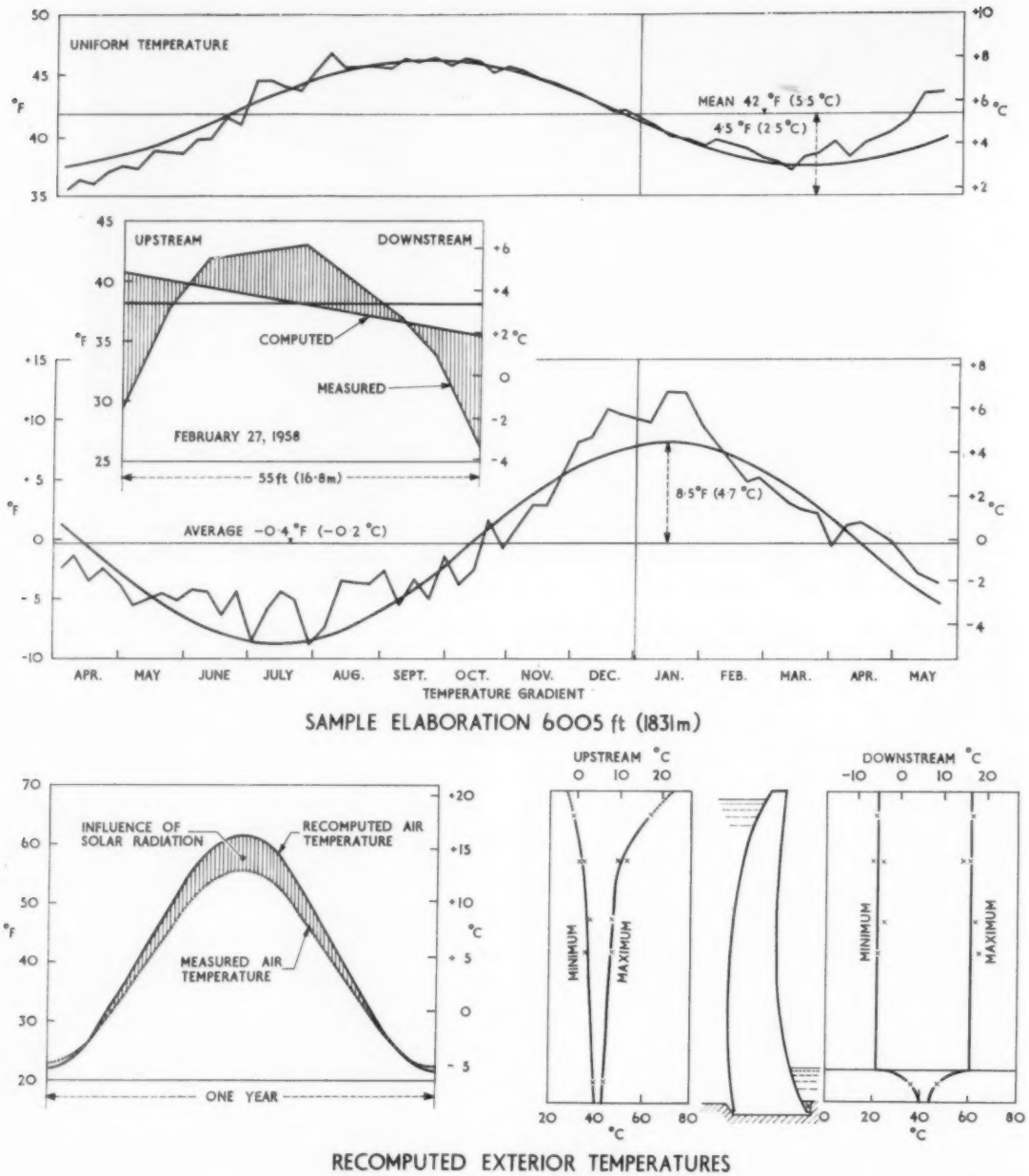



*Fig. 12. Evaluation of temperature measurements for the steady thermal state*

exhibits appreciable permanent deformations.

The numerous thermometers served the dual purpose of checking the effectiveness of the temperature-control method adopted by embedded pipes and of furnishing data as to the subsequent thermal behaviour of the dam after having reached thermal equilibrium. In this sense the evolution of the temperatures across six selected sections was analysed as shown in Fig. 12 for one of them. First the actual temperature distributions were approximated to linear ones having the same areas and centres of gravity. These calculations were performed for all dates of measurement within a period of more than a year on an electronic computer. The resulting theoretical uniform temperatures and temperature gradients were then plotted against time and approximated by trigonometric functions. By using backwards the formulae given above under the title "Static Analysis" it was finally possible to recompute what must have been the external temperatures. The best fit between the recomputed temperature variation at the downstream face and the actual, measured air temperature is obtained when there is no solar radiation in deep winter and with a diffusivity of the concrete of 0·065 ft²/h (0·006 m²/h), which is 50% more than the value determined previously on test specimens.

# Planning Expanding Electrical Systems

The author extends the Method of Simple Mathematical Models to price and cost analysis in expanding electrical systems, taking into account the integration of hydro-power developments

By DR. CHARLES JAEGER

A NEW technique, "electrical system planning," and a new profession, "the planning engineer," are rapidly developing. Technique and profession both tend to be highly specialised. A review of recent publications[1-12] shows the great diversity of methods of investigation and of points of view developed by this profession.

Short-range optimisation of an electric system, when energy is supplied from different sources, usually covers a period of a week or so[1-8]. Only running costs (mostly fuel or coal consumption and transmission losses) are considered. Directly or indirectly the methods used are based on the calculus of variations and on the basic equation of Euler with special conditions attached. Alternatively, electrical computing machines are used for solving practical problems, but the basic thinking is the same: it is a problem of minimum.

Long-range optimisation (over a few months or even a few years) of electric systems partly or entirely fed by hydro power is based on statistics[9, 10, 11] or on probability[12] calculations. This type of system planning is based on existing power stations, and the problem consists in reducing to a minimum the annual running costs, yearly capital charges being excluded as they cannot be changed or optimised by the system dispatcher.

When considering the future expansion of an existing electric system by the addition of new capacity or additional energy generation, capital costs and yearly charges from capital costs must be considered. Alternative sources for power generation have to be compared, prices and costs analysed. The approach to the cost problem as seen by a specialist entrusted with the design of new power stations is basically different from that of a planning engineer in charge of the economic dispatch of an existing combined hydro-steam system. Methods have to be evolved to suit this particular approach. It is suggested that the basic equations linking installed capacity, generated energy, prices and costs are relatively simple and that a start could be made with a simplified method dealing with the broader aspects of problems of costs and prices. Eventually the designer of new power stations may have to submit his problems to a team of specialised engineers or mathematicians used to dealing with electronic computing machines.

The present paper is an endeavour to simplify the approach to a difficult technical and economic problem by using the so-called method of "simple mathematical models." To start with, much uncertainty is inherent in prices and costs appertaining to an often-distant future, and there is a strong case for developing approximate methods dealing with the many parameters involved. This simplified method will be shown to be generally applicable; the equation introduced with this method can be the starting point for more-detailed investigations, possibly using electronic computers.

The above-mentioned method of simple mathematical models—already recommended in the United States for river system planning—was recently evolved for the analysis of pumped-storage schemes[13, 14, 15]. Later on it was shown that the same method can be used for the analysis of large electric systems in general. Systems with two components were considered first[15, 16]. The purpose of this article is to extend the analysis to wider, more intricate, systems with a greater number of components.

## The Basic Equations for Capacities, Energies, and Prices

The method is based on the use of duration curves and load factors $\theta$. Referring to Fig. 1, a power station with installed capacity $N_i$ generates an energy $E_i$ so that

$$E_i = N_i \theta_i T \text{ with } \theta_i = \frac{1}{N_i T} \int_o^T N dt$$

where $T = 1$ year (or 1 month, 1 week, or 1 day), $\theta =$ the load factor of that particular power station. An electric system with capacity $M$ can be broken down into system components (Fig. 2) with capacities $N_1$, $N_2$, . . . $N_i$ so that

$$M = N_1 + N_2 + \ldots + N_i + \ldots \quad \ldots (1)$$

$$M\theta_s = N_1\theta_1 + N_2\theta_2 + \ldots N_i\theta_i + \ldots \quad \ldots (2)$$

where $\theta_s$ is the system load factor and $\theta_1$, $\theta_2$ . . . $\theta_i$ are the load factors of the components.

When a new station with capacity $N_n$ and load factor $\theta_n$ is added to the system (Fig. 3), changes may occur in any of the components $N_i$ where the load factor $\theta_i$ may become $\theta_i + \Delta\theta_i$. Then

$$\theta_n = \theta_s - \frac{N_i}{N_n} \Delta\theta_i \quad \ldots (3)$$

$N_n$ can be any type of capacity; it can be a base-load or a peak-load station. Depending on the sign of $(\theta_s - \theta_n)$, $\Delta\theta_i$ will be positive or negative.

Equations (1), (2) and (3) illustrate the so-called "Theorem of Energy Areas."

A second group of equations can be added, namely, the price equations such as ($T = 8{,}760$ hours $= 1$ year):

$$k_i = \frac{K_i r_i}{T \theta_i} + k_{ri} \quad \ldots (4)$$

where $k_i$ is the price of 1 kWh generated in a station characterised by ($N_i$, $\theta_i$), and $k_{ri}$ is the running cost for fuel, maintenance, etc., per kWh in the same station. $k_{ri}$ is supposed to depend on the energy (in kWh) generated, whereas $K_i$ is the cost per kW of

installed capacity and $r_i$ a rate of interest. $N_i K_i r_i$ represent all yearly capital charges depending on the station capacity. Introducing a relative value $\epsilon_i = \frac{K_i r_i}{T k_{ei}}$ which characterises the type or quality of energy the formula (4) can be written:

$$k_i = \left(\frac{\epsilon_i}{\theta_i} + 1\right) k_{ei} \qquad \ldots (4a)$$

where $\epsilon_i$ varies from 0·15 for gas turbines to about 2·5 for nuclear power, with $\epsilon_i = 0{\cdot}15$ to 0·50 for steam power stations. When $k_{ei}$ is negligible compared with $k_i$ (for instance, hydro power), then equation (4) becomes

$$k_i = \frac{K_i r_i}{T \theta_i} \qquad \ldots (4b)$$

factors $0{\cdot}45 \leqq \theta_s \leqq 0{\cdot}75$ and to $0{\cdot}15 \leqq \epsilon \leqq 2{\cdot}5$. It clearly shows how much higher the generating cost of peak load is, compared with the base-load price $k_o$. Diagram Fig. 5 is confirmed by the actual energy prices paid for peak load and base load in the area of the European Alps[16].

Starting from the same general equations, the relative generating costs of energy generated by two different energy sources can be analysed and discussed, and the more-economic solution can be found[16]. Additional diagrams have been published dealing with the combination of steam power or nuclear energy with hydro power or with pumped storage[15, 16].

Most of the problems dealt with in previous papers consider a power station with a given capacity $N_n$ generating energy at a requested load factor $\theta_n$ which

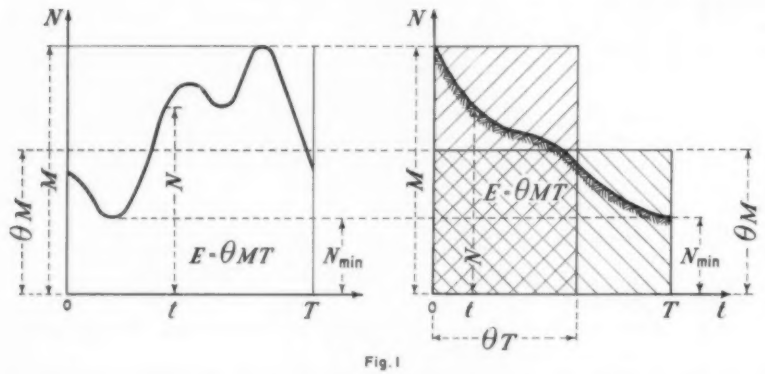



Fig. 1

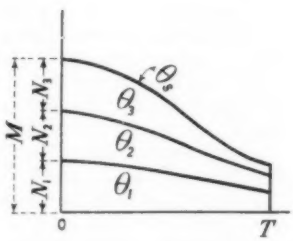



Fig. 2

The combination of equation (4) with equations (1) to (3) permits the discussion of many important problems related to price and cost analysis in large electric systems, including expanding systems. Alternatively, problems can be solved introducing the marginal cost $\Delta K_i$ of an additional capacity $\Delta N_i$ or the marginal price variation $\Delta k_i$ obtained by changing some components of the system. The final aim of any such method is to establish price relations between the different components of the system and to minimise overall costs, when the main characteristics ($E_i$, $N_i$, $\theta_i$) of the system and its components are known or can be estimated.

The method was first used to study the economics of pumped storage[13, 14, 15, 17]. Later it has been used for a more general approach to the economics of electrical systems. The purpose of this paper is to extend the analysis to more complicated systems where more than two components are involved.

## Some Typical Price Problems Involving One or Two Sources of Energy

The price of base-load energy generated by a station working with a load factor $\theta = 1$ is $k_o = (1 + \epsilon)\, k_e$. This price can be compared with the price $k_p = \left(\frac{\epsilon}{\theta_p} + 1\right) k_e$ for peak-load energy of the same nature (same $\epsilon$ value and same $k_e$) where $\theta_p$ is the load factor for short-time peak energy. Assuming (Fig. 4) the peak capacity $N_P$ to be only one-third of the total installed capacity $M$, and assuming in addition $M = N_B + N_1 + N_P$, with $N_B = N_1 = N_P = M/3$, it can be shown that the ratio $k_p/k_o$ depends mainly on the system load factor $\theta_s$ and on $\epsilon$. The diagram Fig. 5 refers to load is to be added to an expanding system ($M + N_n$) with a load factor $\theta_s$. Alternatives are compared without including the changes of structure and prices caused to occur in the larger system and its other components. If this larger system is to be considered too, the method has to be generalised as shown below.

## Shifting of Power, Energy and Prices in an Expanding Electric System with *n* Components

This section (Fig. 6) deals with an expanding electric system that can be broken down into many components and where the introduction of a new additional component ($\Delta N$, $\theta$) has wider repercussions on the whole system ($M$, $\theta_s$).

Any energy area ($M$, $\theta_s$) limited by a true duration curve and broken down into components $N_B$, $N_{n1}$, $N_k$, $N_{n2}$, $N_1$, $N_{n3}$ . . . $N_P$ (Fig. 7a) can also be represented by area-equivalent rectangles (Fig. 7b), all the energy areas $E_i = N_i\ \theta_i$ remaining the same. It is implicitly assumed here, but not proved mathematically, that, vice-versa, any energy-area diagram like Fig. 7b can be transformed into an area diagram like Fig. 7a, limited by a true duration curve, provided that the $\theta_s$ and all the $\theta_i$ are the same for both diagrams. Prices $k_i$ per kWh generated are shown in diagram Fig. 7c, and total generating costs $C_i$ for each component are shown in Fig. 7d where each area represents yearly costs $C_i = E_i\ k_i = N_i\ K_i\ r_i + k_{ei}\ N_i\ \theta_i\ T$. The whole area $C_{tot.} = \Sigma\, C_i$ has to be reduced to a minimum, following changes in energies, prices and costs year after year as the system expands. The problem is obviously most complicated. Short cuts and approximate methods, as shown below, are highly desirable.

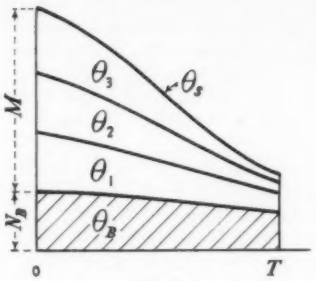


Fig.3a

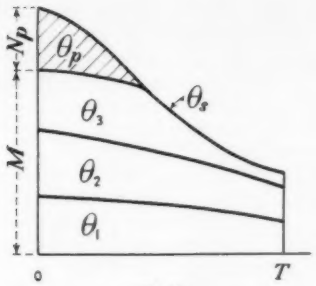


Fig.3b

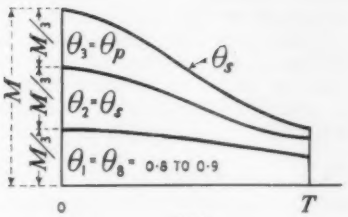


Fig.4

GROUPING OF COMPONENTS

A preliminary remark may facilitate further discussion. It is assumed in Fig. 7a that modifications of the capacity $N_l$ and $N_K$ and of the load factors $\theta_l$, $\theta_K$ may occur. The other components like $N_B$, $N_{n1}$, $N_{n2}$, $N_{n3}$ . . . $N_P$ can be grouped like this:

$$M = N_B + N_{n1} + N_K + N_{n2} + N_l + N_{n3} + \ldots N_P$$
$$M\theta_s = N_B\theta_B + N_{n1}\theta_{n1} + N_K\theta_K + N_{n2}\theta_{n2} + N_l\theta_l + N_{n3}\theta_{n3} \ldots N_P\theta_P$$

with

$$N_o = N_B + N_{n1} + N_{n2} + N_{n3} + \ldots N_P$$
$$E_o = N_o\theta_o = N_B\theta_B + N_{n1}\theta_{n1} + N_{n2}\theta_{n2} + N_{n3}\theta_{n3} + \ldots N_P\theta_P$$

so that ultimately

$$M = N_o + N_K + N_l$$
$$E = M\theta_s = N_o\theta_o + N_K\theta_K + N_l\theta_l \qquad \ldots (5)$$

It is important to stress that the order in which the components of $N_o$ and $N_o\theta_o$ are being added is immaterial.

CHANGES OF CAPACITIES $\Delta N_K$, $\Delta N_l$ CAUSE NO CHANGES IN $E_o = N_o\theta_o$

In this paragraph it is assumed that no change occurs in $E_o = N_o\theta_o$ and also implicitly assumed that prices and costs in that area remain also unchanged, or, alternatively, that such changes are immaterial for the further discussion of the cost problem. This basic assumption was implicitly made for most problems dealt with in previous papers[14, 15, 16].

The opposite is likely to occur very often, and conditions then prevailing are discussed in the following paragraph.

CHANGES OF CAPACITY $\Delta N_K$, $\Delta N_l$ CAUSE A LOAD-FACTOR CHANGE $\Delta\theta_o$

Let us assume that the capacity of two system components $N_K$ and $N_l$ is being increased to $N_K + \Delta N_K$ and $N_l + \Delta N_l$; the capacity of component $N_o$ and the system load factor $\theta_s$ remain unchanged. The new system can be described by three equations:

$$\Delta N = \Delta N_K + \Delta N_l$$
$$M + \Delta N = M + \Delta N_K + \Delta N_l = N_o + N_K + \Delta N_K + N_l + \Delta N_l$$
$$E + \Delta E = (M + \Delta N_K + \Delta N_l)\ \theta_s = N_o\ (\theta_o + \Delta\theta_o) + E_K + \Delta E_K + E_l + \Delta E_l \qquad \ldots (6)$$

where

$$\Delta E_K = \Delta N_K\ (\theta_K + \Delta\theta_K) + N_K\ \Delta\theta_K, \text{ etc.}$$

Subtracting (5) from (6) yields:

$$\Delta E = (\Delta N_K + \Delta N_l)\ \theta_s = N_o\ \Delta\theta_o + \Delta E_K + \Delta E_l$$

$\Delta E_K$ and $\Delta E_l$ can be positive, nought, or negative, but $\Delta E$ is supposed to be positive.

Those components $N_o$ where no change of capacity occurs work now with a changed load factor and

$$\Delta\theta_o = \frac{\Delta N_K + \Delta N_l}{N_o}\cdot\theta_s - \frac{\Delta E_K + \Delta E_l}{N_o} \qquad \ldots (7)$$

This equation can obviously be extended to more than two changes in the components and be written:

$$\Delta\theta_o = \frac{1}{N_o}\ (\Delta E - \Sigma\Delta E_K) =$$
$$\theta_o = \frac{\Delta N_K + \Delta N_l + \ldots}{N_o}\cdot\theta_s - \frac{\Delta E_K + \Delta E_l + \ldots}{N_o}$$
$$= \frac{\Delta E}{N_o} - \frac{1}{N_o}\ (\Delta N_K\theta_K' + \Delta N_l\theta_l' + \ldots) =$$
$$= \frac{1}{N_o}\ \Sigma\ (\Delta N)\ \theta_s - \frac{1}{N_o}\ \Sigma\ (\Delta N\theta') \qquad \ldots (7a)$$

When only one component is changed, then obviously

$$\Delta\theta_o = \frac{\Delta N}{N_o}\ \theta_s - \frac{\Delta E_K}{N_o} = \frac{\Delta N}{N_o}\ (\theta_s - \theta_K') \qquad \ldots (7b)$$

where $\theta_K'$, $\theta_l'$ . . . are the load factors of the new components ($\Delta E_K = \Delta N\theta_K'$, etc.).

This equation (7b) is obviously equivalent to equation (3). In particular, we get from equation (7a) that $\Delta\theta_o = 0$ when $\Delta E = \Delta E_K + \Delta E_l + \ldots = \Sigma\Delta E_K$. $\Delta\theta_o$ now refers to the total sub-system $N_o$ which can be written as follows: Before extension of the system, $N_o$, in the most general case, is given by an equation like:

$$N_o = N_1 + N_2 + \ldots + N_i + N_j + \ldots$$
$$N_o\ \theta_o = N_1\theta_1 + N_2\theta_2 + \ldots + N_i\theta_i + N_j\theta_j + \ldots$$

After extension of the system the previous equation becomes:

$$N_o\ (\theta_o + \Delta\theta_o) = N_1\theta_1 + N_2\theta_2 + \ldots + N_i\ (\theta_i + \Delta\theta_i) + N_j\ (\theta_j + \Delta\theta_j) + \ldots$$

We therefore implicitly assume that some stations

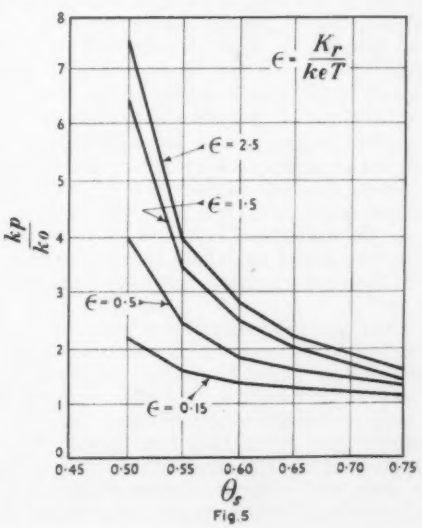


Fig.5

$N_1, N_2 \ldots$ are unable to generate more energy. (This would be the case with some hydro-power stations, mainly stations with reservoirs, which already generate all possible energy. For them $E_1 = N_1\theta_1$, $E_2 = N_2\theta_2 \ldots$ remains constant.) The shifting of energy is therefore taken over by the other stations of the system (possibly steam or gas-fired thermal stations) and

$$N_o\,\Delta\theta_o = N_i\,\Delta\theta_i + N_j\,\Delta\theta_j + \ldots = (\Delta N_K + \Delta N_l + \ldots)\,\theta_s - (\Delta E_K + \Delta E_j + \ldots) = \Delta E - (\Delta E_K + \Delta E_l + \ldots) \quad \ldots (8)$$

Some useful information can be gained from a simple discussion of these equations. Let us first consider equations (7a) and (8). From equation (7a) $\Delta\theta_o = (\Delta E - \Sigma E_K)/N_o$ it can be seen that $\Delta\theta_o$ depends mainly on $\Delta E = \Delta N\theta_s$ = the energy increases required by the expanding total demand minus the $\Sigma\Delta E_K$ of the additional energy generated in the system.

$\Delta\theta_o$ can be positive, nought, or negative. In particular, as mentioned before,

$$\Delta\theta_o = 0 \text{ when } \Delta E = \Sigma\Delta E_K.$$

On the other hand, equation (8) can be written:

$$N_o\,\Delta\theta_o = N_i\,\Delta\theta_i + N_j\,\Delta\theta_j + \ldots = N_i\,(\Delta\theta_o + \Delta\Delta\theta_i) + N_j\,(\Delta\theta_o + \Delta\Delta\theta_j) + \ldots \quad \ldots (9)$$

introducing $\Delta\theta_i = \Delta\theta_o + \Delta\Delta\theta_i \ldots$ etc.

Then (8) becomes:

$$N_o\,\Delta\theta_o = (N_i + N_j + \ldots)\,\Delta\theta_o + N_i\,\Delta\Delta\theta_i + N_j\,\Delta\Delta\theta_j + \ldots$$

and finally

$$(N_1 + N_2 + \ldots)\,\Delta\theta_o = N_i\,\Delta\Delta\theta_i + N_j\,\Delta\Delta\theta_j + \ldots \quad \ldots (10)$$

showing how $\Delta\theta_i$, $\Delta\theta_j \ldots$ must differ from $\Delta\theta_o$. In particular, when $\Delta\theta_o = 0$, then:

$$\Delta\Delta\theta_i = -\frac{N_j}{N_i}\,\Delta\Delta\theta_j + \ldots \quad \ldots (11)$$

which shows that some of the $\Delta\Delta\theta$ will be positive, the others being negative to keep the balance.

THE EQUATIONS OF COSTS AND PRICES. DISCUSSION

Before any change occurs in the system, the equation of costs is ($T = 1$ year $= 8{,}760$ hours):

$$C_{tot.} = N_1\theta_1\,T\,k_1 + N_2\theta_2\,T\,k_2 + \ldots + N_i\theta_i\,T\,k_i + N_l\theta_l\,T\,k_j + \ldots + N_K\theta_K\,T\,k_K + N_l\theta_l\,T\,k_l + \ldots \quad \ldots (12)$$

It now becomes, after the changes occur:

$$C_{tot.}' = N_1\theta_1\,T\,k_1' + N_2\theta_2\,T\,k_2' + \ldots + N_i(\theta_i + \Delta\theta_i)\,T\,k_i' + N_j(\theta_j + \Delta\theta_j)\,T\,k_j' + (E_K + \Delta E_K)\,k_K' + (E_l + \Delta E_l)\,k_l' + \ldots \quad \ldots (12a)$$

This equation can be discussed from many different angles. $C_{tot.}$ may represent the total generating costs, including the yearly capital charges $K_i\,r_i\,N_i$, or the equation giving $C_{tot.}$ may be discussed in order to reduce to a minimum the yearly running expenses, irrespective of the yearly capital charges, which the planning engineer is not able to reduce or modify and therefore excludes from his calculations. Alternatively, the same equation can be analysed introducing the selling prices or market value $k^*$ of the energy.

The equation $\Delta C_{tot.} = \Sigma\,N_i\,\theta_i\,(k_i^* - k_i) \quad \ldots (13)$ will then be maximised. (A typical price pattern, based on the ratio of peak load factor $\theta_p$ to base load factor $\theta_B$ has been discussed in a previous paper[17] and shown in Fig. 4.)

In the previous discussion it was implicitly assumed that the normal expansion of the electric system can proceed without financial restrictions. Such restrictions may be unavoidable, and the management of the electric distribution network may have to consider how to slow down the normal system expansion or how to modify the demand curve in order to reduce costs and expenses. A modification of the system load factor $\theta_s$ may sometimes be advisable; the analysis of equations (12) and (13) may give some clues on how to modify the pattern of prices $k_i^*$ with a view of inducing consumers to modify their power and load requirements. In the more general case, the analysis of equations (8), (9), and (10) is so intricate that the use of digital computers will have to be considered.

When examining the cost and price problems from the angle of power generation, there is no reason why the generating costs of the components $N_1, N_2 \ldots$ should be different before and after system expansion. Therefore $k_1' = k_1$, $k_2' = k_2 \ldots$ The differential generating cost:

$$\Delta C_{tot.} = C_{tot.}' - C_{tot.} \quad \ldots (14)$$

shows that all terms like $N_1\theta_1\,T\,k_1$, $N_2\theta_2\,T\,k_2$ can be cancelled ($\Delta C_1 = 0$, $\Delta C_2 = 0 \ldots$).

This conclusion would be different if market prices $k^*$ instead of generating costs per unit $k$ were considered. When a system expands, mainly through addition of base load, components at the peak of the load-duration curve may have to work shorter hours. Alternatively, a hydro-power component generating constant energy $\Delta E_1$, $\Delta E_2 \ldots$ will be slightly displaced in the pattern of load distribution; the market price for the energy may then be different because market prices depend on the pattern of relative prices, as shown elsewhere[17]. Additional benefits can be gained by carefully expanding systems including hydro-power generation. Conditions are quite different for steam-generated energy (see also paragraph "Market Price Variations" below).

Let us now consider the terms like $N_i\theta_i\,T\,k_i$ for which $\Delta N_i = 0$, but where it is to be expected that $\Delta\theta_i \neq 0$.

The generating costs before expansion of the system are:

$$k_i = \frac{K_i\,r_i}{\theta_i\,T} + k_{ei} \text{ and}$$

$$k_i' = \frac{K_i\,r_i}{(\theta_i + \Delta\theta_i)\,T} + k_{ei}'$$

after the expansion of the system.

When $k_{ei} = k_{ei}' = 0$ (hydro power), then ($T = 1$):

$$N_i\,(\theta_i + \Delta\theta_i)\,k_i'\,\frac{\theta_i + \Delta\theta_i}{\theta_i + \Delta\theta_i}\,K_i\,r_i = N_i\,K_i\,r_i = N_i\,\theta_i\,k_i \quad \ldots (15)$$

There is obviously no change in the yearly generating cost of this type of energy. In cases where the running costs are not negligible (assuming $T = 1$):

$$\Delta C_i = N_i\,(\theta_i + \Delta\theta_i)\,k_i' - N_i\,\theta_i\,k_i = N_i\,\frac{K_i\,r_i\,(\theta_i + \Delta\theta_i)}{\theta_i + \Delta\theta_i} + k_{ei}'\,N_i\,(\theta_i + \Delta\theta_i) - N_i\,\frac{K_i\,r_i\,\theta_i}{\theta_i} - N_i\,\theta_i\,k_{ei} = N_i\,[(\theta_i + \Delta\theta_i)\,k_{ei}' - \theta_i\,k_{ei}] \quad \ldots (15a)$$

In the likely case where $k_{ei}' = k_{ei}$, the difference in generating cost becomes:

$$\Delta C_i = N_i\,\Delta\theta_i\,k_{ei} \quad \ldots (15b)$$

for all the terms of that category.

The total yearly costs are less when $\Delta\theta_i < 0$. They increase when $\Delta\theta_i > 0$.

This, incidentally, is the mathematical formulation and justification of the price policy followed by the British Central Electricity Generating Board when old low-efficiency steam stations are kept working on the British power system for shorter hours every year while new base-load capacity is brought into the system.

For the terms of the last category ($N_K$, $N_l$ . . . ), for which an increase of capacity $\Delta N_K$, $\Delta N_l$, and probably an increase of energy $\Delta E_K=(N_K+\Delta N_K)\times(\theta_K+\Delta\theta_K)-N_K\,\theta_K$ is to be considered, the differential yearly cost is:

$$\Delta C_K=(N_K+\Delta N_K)(\theta_K+\Delta\theta_K)\,k_K''-N_K\,\theta_K\,k_K=$$
$$=N_K(\theta_K+\Delta\theta_K)\left[\frac{K_K\,r_K}{(\theta_K+\Delta\theta_K)}+k_{eK}'\right]+$$
$$\Delta N_K(\theta_K+\Delta\theta_K)\left[\frac{K_K'\,r_K}{(\theta_K+\theta_K)}+k_{eK}'\right]-$$
$$N_K\,\theta_K\left[\frac{K_K\,r_K}{\theta_K}+k_{eK}\right]=$$
$$=N_K\,K_K\,r_K+N_K(\theta_K+\Delta\theta_K)\,k_{eK}'+\Delta N_K\,K_K'\,r_K$$
$$+\Delta N_K(\theta_K+\Delta\theta_K)\,k_{eK}'-N_K\,K_K\,r_K-N_K\,\theta_K\,k_{eK}$$
$$\Delta C_K=N_K\,\Delta\theta_K\,k_{eK}+\Delta N_K\,K_K'\,r_K+\Delta N_K(\theta_K+\Delta\theta_K)\,k_{eK} \qquad \ldots (16)$$

When additional base load is introduced in the system ($\theta_B>\theta_s$), the $\Delta\theta_o$ given by formula (7) or (7a) will be negative. So will be most of the $\Delta\theta_i$ and $\Delta\theta_j$ in formula (8). When the stations $i$, $j$ are steam stations, this will lead—as expected—to additional savings $\Delta C_i\cong N_i\,\Delta\theta_i\,k_{ei}$ in the system. When some of the stations in the system are hydro-power stations, it is to be expected that for them $\Delta E_1=\Delta E_2=\ldots=0$ and $\Delta\theta_1=\Delta\theta_2=\ldots=0$. For a given $\Delta\theta_o$ value (calculated with formula 7) the $\Delta\Delta\theta_i$, $\Delta\Delta\theta_j$ given by formula (13) will become larger, and the load shifting will be felt mainly by the steam stations in the system. This shifting of the load can be estimated with equations (7) to (13).

When there are no steam stations (or gas-fired thermal stations) on the system, the balance of capacity and energy has to be re-established by building

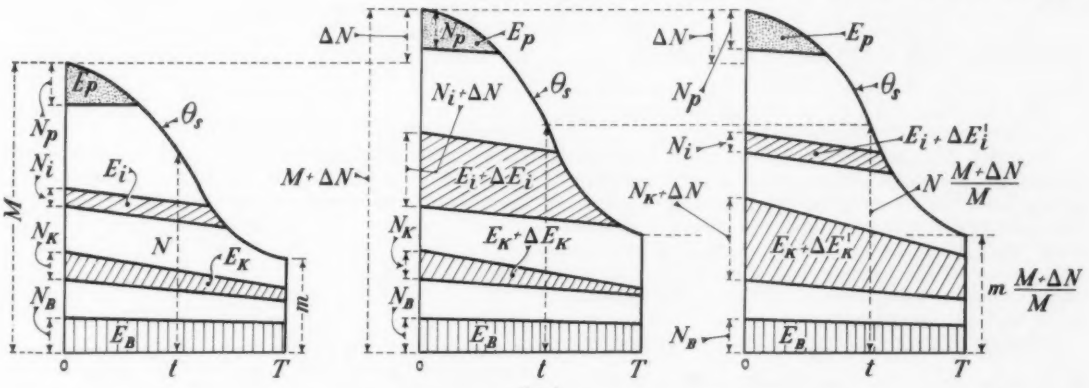



Fig. 6

assuming the prices $k_{eK}'\neq k_{eK}$ not to be the same.

In the case when $k_{eK}\cong k_{eK}'$ (at least in first approximation), $\Delta C_K$ becomes:

$$\Delta C_K=[N_K\,\Delta\theta_K+\Delta N_K(\theta_K+\Delta\theta_K)]\,k_{eK}+\Delta N\,K_K'\,r_K=$$
$$\Delta E_K\,k_{eK}+\Delta N_K\,K_K'\,r_K \qquad \ldots (16a)$$

when the additional energy generated is:

$$\Delta E_K=N_K\,\Delta\theta_K+\Delta N_K(\theta_K+\Delta\theta_K)$$

The meaning of the simplified formula (16a) is obvious. The increase in cost can also be written:

$$\Delta C_K=(\Delta E_K+\Delta N_K\,\epsilon_K')\,k_{eK}$$

The price per unit of additional energy becomes:

$$\frac{\Delta C_K}{\Delta E_K}=\left(1+\frac{\Delta N_K}{\Delta E_K}\,\epsilon_K'\right)k_{eK} \qquad \ldots (17)$$

where $\epsilon_K'=K_K'\,r_K/k_{eK}$.

All these equations are simpler when it can be assumed that $k_{eK}=0$, as usually can be done for hydro-power stations. In such a case:

$$\Delta C_K\cong\Delta N_K\,K_n'\,r_n \qquad \ldots (17a)$$

Summarising this discussion, the increase in cost to the system caused by adding the capacities $\Delta N_K$, $\Delta N_l$ . . . generating the energies $\Delta E_K$, $\Delta E_l$ . . . is:

$$\Delta C_{tot.}=\Delta C_i+\Delta C_j\ldots+\Delta C_K+\Delta C_l+\ldots$$

with $\Delta C_1=\Delta C_2=\ldots=0$.

This $\Delta C_{tot.}$ includes not only cost increases in the components $K$ and $l$ but also changes in costs occurring anywhere in the system.

In many cases, simplified formulae can be used to determine the numerical value of $\Delta C_{tot.}$. The unit price of the additional energy is then $\Delta C_{tot.}/\Delta E$.

## Market-Price Variations

A further study of equations (7) to (9) leads to some additional remarks.

additional hydro-power peak-load and/or pumping stations. This is a case which has been dealt with extensively in some previous papers[1, 2, 3, 5].

Equation (9) can also be used to study the financial earnings by comparing the energy market prices and the energy generating costs.

Let us assume that in a hydro-power station the load factor $\theta_i$ (or $\theta_K$) is reduced to $\theta_i+\Delta\theta_i$ with $\Delta\theta_i<0$. Alternatively the capacity $N_K$ of a hydro-power scheme can be increased to $N_K+\Delta N_K$ and the load factor $\theta_K$ may drop to $\theta_K+\Delta\theta_K$, with $\Delta\theta_K<0$.

The market value of the new energy can be estimated by comparison with alternative steam power. A scale of alternative unit prices for steam-generated energy can be established on the following remarks:

An additional capacity $\Delta N$ would cause additional yearly costs $\frac{K\,r}{T}$ and the unit energy would cost ($T=$ 1 year):

$$\frac{K\,r}{\theta+\Delta\theta}+k_e=\left(\frac{\epsilon}{\theta+\Delta\theta}+1\right)k_e$$

This price can be compared with the cost of base-load energy for $\theta=1$, which yields as unit cost:

$$K_o\,r+k_{eo}=(\epsilon_o+1)\,k_{eo}$$

The relative price scale is therefore given by a function like:

$$\frac{1+\dfrac{\epsilon}{\theta+\Delta\theta}}{1+\epsilon_o}\cdot\frac{k_e}{k_{eo}}$$

This ratio $k_e/k_{eo}$ depends mainly on the relative thermal efficiency of large base-load stations and smaller stations running at a reduced load factor $\theta+\Delta\theta$, when

the steam stations may have to be heated during the night or off-peak hours to keep them ready and under pressure. The ratio $\frac{\epsilon}{\epsilon_o}=K/K_o$ depends on the capital cost of equipment for smaller stations as compared with the capital cost of large base-load stations per kW installed.

Families of curves can be traced for given parameters $\Delta N/N_o$ ($N_o$ = capacity of large base-load stations ≅ 300 to 500 MW for British conditions). These curves would yield standard energy prices for steam generation to be compared with alternative solutions (hydro power).

The whole theory can be developed further considering the expansion over a series of years and progressive amortisation of the capital costs. Slow variations of the system load factor $\theta_o$ can also be dealt with.

## Selected Examples of Price and Cost Problems

### Price and Cost Equations when the Capacity of One Component ($N_i\theta_i$) is Increased, the Components being Considered Separately

A number of selected practical examples have been discussed in previous papers, most of them analysing typical situations[15, 16, 17]. In the following examples the approach to price equations is slightly different from what has been published before, the emphasis being now on the extension of a capacity $N$ to the capacity $N+\Delta N$ and the analysis of the resulting price and cost equations.

A system component $(N_i\theta_i)=E_i$ is generating energy at a price $\frac{K_i r_i}{\theta_i T}+k_{ei}$. The component's capacity is increased to $N_i+\Delta N$ and $K_i'$ is the cost per additional kW. The new energy price will be:

$$\frac{N_i K_i r_i+\Delta N K_i' r_i}{(N_i+\Delta N)(\theta+\Delta\theta)T}+k_{ei}'$$

The component's expansion is an acceptable one if unit prices for energy are lower or the same as before, or when:

$$\frac{\frac{N_i K_i r_i+\Delta N K_i' r_i}{(N_i+\Delta N)(\theta_i+\Delta\theta_i)T}+k_{ei}'}{\frac{K_i r_i}{\theta_i T}+k_{ei}}\leqslant 1 \qquad \ldots (18)$$

or $$\frac{N_i K_i r_i+\Delta N K_i r_i}{(N_i+\Delta N)(\theta_i+\Delta\theta_i)T}+k_{ei}'\leqslant\frac{K_i r_i}{\theta_i T}+k_{ei}$$

or $$\frac{(N_i K_i r_i+\Delta N K_i' r_i)\theta_i T}{(N_i+\Delta N)(\theta_i+\Delta\theta_i)T K_i r_i}\leqslant 1 \qquad \ldots (19)$$

when $k_{ei}=k_{ei}'$.

This last equation shows the fuel costs and other running costs to be immaterial if they are the same before and after the component's expansion. This then leads to:

$$\frac{1+\frac{\Delta N}{N_i}\frac{K_i'}{K_i}}{\left(1+\frac{\Delta N}{N_i}\right)\left(1+\frac{\Delta\theta_i}{\theta_i}\right)}<1$$

$$\frac{\Delta N}{N_i}\cdot\frac{K_i'}{K_i}<\frac{\Delta N}{N_i}\left(1+\frac{\Delta\theta_i}{\theta_i}\right)+\frac{\Delta\theta_i}{\theta_i} \text{ and}$$

$$\lambda=\frac{K_i'}{K_i}<\left(1+\frac{\Delta\theta_i}{\theta_i}\right)+\frac{N_i\Delta\theta_i}{\Delta N\,\theta_i}=$$

$$1+\frac{\Delta\theta}{\theta_i}\left(\frac{N_i+\Delta N}{\Delta N}\right) \qquad \ldots (19a)$$

where $\lambda$ represents the ratio of capital costs for the sources $\Delta N$ and $N$.

On the other hand, the energy equations yield:

$$\Delta E_i=\Delta N\,\theta_i+(N_i+\Delta N)\,\Delta\theta_i$$

$$\frac{\Delta\theta_i}{\theta_i}=\frac{\Delta E_i/\theta_i-\Delta N}{N_i+\Delta N}$$

And therefore:

$$\lambda=\frac{K_i'}{K_i}<1+\frac{\Delta E_i/\theta_i-\Delta N}{\Delta N}=\Delta E_i/\theta_i\,\Delta N \qquad \ldots (20)$$

When the new capacity $\Delta N$ is supposed to generate energy at the same load factor $\theta_i$ as $N$, then: $\Delta E_i=\Delta N\,\theta_i$ and

$$\lambda=\frac{K_i'}{K_i}<1+\frac{\Delta N-\Delta N}{\Delta N}=1$$

More generally: assuming $\Delta E$ to be $\Delta E=\alpha\,\Delta N\,\theta_i$, then $K_i'/K_i<\alpha$ is the required condition, a very simple result.

Summarising this discussion, when contrarily $\Delta E=0$ (enlargement of a hydro-power station capacity without increasing the total energy output), then:

$$\lambda=\frac{K_i'}{K_i}<1-1=0$$

a condition which is meaningless. In such a case it is suggested that the cost ratio $\lambda$ could be compared with the ratio of the market value for energies $k^{**}/k^{*}$ which for water power is about

$$\frac{k^{**}}{k^{*}}=\frac{\theta_i}{\theta_i+\Delta\theta_i}=\frac{N_i+\Delta N}{N_i}\,(k_{ei}=0)$$

and finally yields:

$$\frac{K_i'}{K_i}<1 \text{ (for } k_{ei}=0)$$

as expected. It is a peculiarity of many hydro-power designs that, within limits, the cost $K_i'$ of additional capacity $\Delta N$ is less than the cost $K_i$ of the capacity $N$ installed; such designs are likely to be selected for gaining additional capacity.

### Economic Capacity of a Conventional Run-of-River Station

This case has been dealt with in a previous paper[15]. It is worth while showing the identity of the method used at that time with the more general one proposed here.

In the case where $k_{ei}=k_{ei}'$ (or in the case where both can be neglected, as usual in the first instance with conventional hydro power), the equation (18) can be written:

$$\frac{\frac{N K r+\Delta N K' r'}{E+\Delta E}}{\frac{N K r}{E}}\leqslant 1$$

which obviously leads to:

$$(N K r+\Delta N K' r')E<N K r(E+\Delta E)$$

and finally to:

$$\frac{\Delta N K' r' E}{N K r\,\Delta E}\leqslant 1 \text{ or}$$

$$\frac{\frac{\Delta N K' r'}{\Delta E}}{N K r/E}\leqslant 1$$

It is therefore sufficient to prove that the cost $\Delta N\,K'\,r'$ of the additional energy $\Delta E$ obtained by expanding to $N+\Delta N$ the capacity $N$ of the run-of-river plant, is not more than the cost of the bulk energy $E$ generated by the station with a capacity $N$.

This is the approach used in the previous article where the energy $E$ generated by a run-of-river sta-

tion (Fig. 8) is shown to be $E = 365\ \theta_o^*\ N$ (where $\theta_o^*$ is the station load factor) represented by the shaded area under the power/duration curve characterising the run-of-river station† ($T = 365$ days).

The capital cost for building the station with the capacity $N$ is $N\ K\ r$ and the unit energy price $N\ K\ r/E$. The capital cost for the additional capacity $\Delta N$ is $\Delta N\ K'\ r'$ and the unit price $\Delta N\ K'\ r'/\Delta E$ with $\Delta E \cong (365 - t^*)\ \Delta N$. The price ratio for the unit energy should be:

$$\frac{k'}{k} = \frac{\Delta N\ K'\ r'}{N\ K\ r} \cdot \frac{E}{\Delta E} = \frac{\Delta N\ K'\ r'\ N\ 365\ \theta_o^*}{N\ K\ r\ \Delta N\ (365 - t^*)} < 1$$

$$\frac{k'}{k} = \frac{K'\ r'\ 365\ \theta_o^*}{K\ r\ (365 - t^*)} < 1$$

which is the formula given in a previous paper[15].

$$< N_K\ K_K\ r_K + k_{eK}\ N_K\ (\theta_K + \Delta\theta_K^*)\ T + N_l\ K_l\ r_l + \Delta N\ K_l^*\ r_l + k_{el}\ (N_l + \Delta N)\ (\theta_l + \Delta\theta_l^*)\ T$$

Writing $K_K^*\ r_K = \lambda\ K_l^*\ r_l$, then the price equation becomes:

$$\Delta N\ (K_K^* - K_l^*)\ r = \Delta N\ (\lambda - 1)\ K_l^*\ r_l$$

$$\leqslant k_{el}\ T\ [\Delta N\ (\theta_l + \Delta\theta_l^*) + N_l\ (\Delta\theta_l^* - \Delta\theta_l)] - k_{eK}\ T\ [\Delta N\ (\theta_K + \Delta\theta_K) + N_K\ (\Delta\theta_K - \Delta\theta_K^*)]$$

This approach is more general than some examples calculated in previous articles. For example the case where $N_l \neq 0$ (steam) and $N_K = 0$ has been calculated[3, 5], for $\Delta N_K = \Delta N_l$ (water or steam). The condition $N_K = 0$ causes in addition $\theta_K = 0$. The case of pumped storage has been dealt with specially.

A more general approach is possible assuming $\Delta N = \Delta N_K + \Delta N_l$ with $\Delta N_K\ \Delta N_l \neq 0$. The problem would be to minimise the overall costs and yearly expenses by varying a parameter $\mu = \Delta N_K / \Delta N_l$.

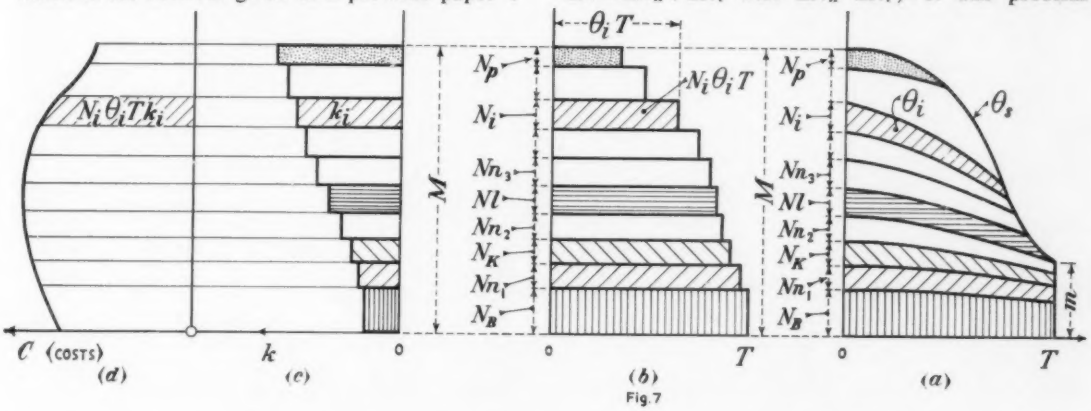


Fig. 7

### Comparative Prices for two Alternative Combinations of Power Generation

An additional capacity $\Delta N$ and energy $\Delta E$ is required. According to one alternative, this can be obtained by adding a capacity $\Delta N$ to the component $N_K$, now working at a load factor $\theta_K + \Delta\theta_K$. A component $N_l$ (with $\Delta N_l = 0$) would work at capacity $\theta_l + \Delta\theta_l$ to help generate the required energy. The capital costs are $K_K$ for the capacity $N_K$ and $K_K^*\ r_K$ for the capacity $\Delta N$, and $K_l$ for $N_l$. The alternative would be to add $\Delta N$ to the component $N_l$ at a load factor $\theta_l + \Delta\theta_l^*$, when the component $N_K$ ($\Delta N_K = 0$) would work at a factor $\theta_K + \Delta\theta_K^*$. It is therefore assumed that always $\Delta N_K$. $\Delta N_l = 0$.

The capital costs are now $K_K$ for $N_K$, $K_l$ and $K_l^*$ for $N_l$ and $\Delta N_l$. $k_{eK}$ and $k_{el}$ are the running costs for components $K$ and $l$ in both alternatives.

The equation of energies yields:

$$\Delta N\ \theta_s = \Delta E = (N_K + \Delta N)\ (\theta_K + \Delta\theta_K) + N_l\ (\theta_l + \Delta\theta_l) - (N_K\ \theta_K + N_l\ \theta_l)$$

$$= N_K\ (\theta_K + \Delta\theta_K^*) + (N_l + \Delta N)\ (\theta_l + \Delta\theta_l^*) - (N_K\ \theta_K + N_l\ \theta_l)$$

or $\Delta E$

$$= \Delta N\ (\theta_K + \Delta\theta_K) + N_K\ \Delta\theta_K + N_l\ \Delta\theta_l = N_l\ \Delta\theta_l + \Delta E_K$$

$$= \Delta N\ (\theta_l + \Delta\theta_l^*) + N_l\ \Delta\theta_l^* + N_K\ \Delta\theta_K^* = N_K\ \Delta\theta_K^* + \Delta E_l^*$$

or $$\Delta N\ (\theta_s - \theta_K) = N_l\ \Delta\theta_l + \Delta\theta_K\ (N_K + \Delta N) \quad \ldots (21)$$

$$\Delta N\ (\theta_s - \theta_l) = N_K\ \Delta\theta_K^* + \Delta\theta_l^*\ (N_l + \Delta N) \quad \ldots (22)$$

The first power and energy combination is the cheaper one when:

$$N_K\ K_K\ r_K + \Delta N\ K_K^*\ r_K + k_{eK}\ (N_K + \Delta N)\ (\theta_K + \Delta\theta_K)\ T + N_l\ K_l\ r_l + k_{el}\ N_l\ (\theta_l + \Delta\theta_l)\ T$$

### Numerical Example

An electrical system with installed capacity $M = 1$ and load factor $\theta_s = 0{\cdot}5$ is divided into three components. The base load $N_1 = 1/3\ M$, $\theta_1 = 0{\cdot}7$ is steam-generated energy. The second component $N_K = 1/3\ M$, $\theta_K = \theta_s = 0{\cdot}5$ is hydro power ($k_{eK} = 0$). The third component is $N_P = N_o = 1/3\ M$ with $\theta_o = 0{\cdot}3$. The steam-generated energy is characterised by $\epsilon$ values, $\epsilon = \dfrac{K_1\ r_e}{k_{e1}\ T}$, varying from 0·15 to 0·50.

A capacity $\Delta N = 0{\cdot}2\ M$ is to be added so that the system generation is increased by $\Delta E = \Delta N\ \theta_s = 0{\cdot}2 \times 0{\cdot}5\ M = 0{\cdot}1\ M$ ($T = 1$ year = 8,760 hours). A first solution consists in adding hydro power up to a capacity $\Delta N = 0{\cdot}2\ M$ and no steam capacity. This additional capacity generates an energy $\Delta E_K$ so that $0 < \Delta E_K < \Delta E$, the remainder $\Delta E - \Delta E_K = \Delta E_l$ being steam generated. The case $\Delta E_K = 0$ would correspond to a stored reserve of energy which cannot be increased, even increasing the capacity. The case $\Delta E_K > 0$ would correspond to a run-of-river station where an increase in capacity usually causes an additional energy to be available.

The alternative solution would be to add a capacity $\Delta N = \Delta N_l^*$ all steam, with $\Delta E_1^* = \Delta E$, and $\Delta E_K^* = 0$. The first alternative is acceptable when the capital charge ratio $\lambda = \dfrac{K_K\ r_K}{K_l\ r_l}$ obeys the condition ($k_{eK} = 0$):

$$\lambda \leqslant 1 + \frac{1}{\epsilon\ \Delta N}\ [\Delta N\ (\theta_l + \Delta\theta_l^*) + N_l\ (\Delta\theta_l^* - \Delta\theta_l)] \quad \ldots (23)$$

† Load factors are commonly used for characterising the system demand and the system generation. They are introduced here as a fundamental characteristic of run-of-river stations, starting from the flow-duration curve that is then being used to trace the power-duration curve of the run-of-river station.

The first alternative solution is characterised by the equation:

$$\Delta N\,\theta_s = \Delta E = N_l\,\Delta\theta_l + \Delta E_K$$

or

$$\Delta\theta_l = \frac{1}{N_l}\,(\Delta E - \Delta E_K)$$

The second alternative yields $(\Delta E_K{}^* = 0)$

$$\Delta N\,\theta_s = \Delta E = \Delta\theta_l{}^*\,(N_l + \Delta N) + \Delta N\,\theta_l$$

or

$$\Delta\theta_l{}^* = \frac{N\,(\theta_s - \theta_l)}{N_l + \Delta N}$$

with $\theta_s = 0{\cdot}5$, $\theta_l = 0{\cdot}7$, $\theta_K = 0{\cdot}5$, $\theta_o = 0{\cdot}3$, $\Delta N = 0{\cdot}2\ M$, $\Delta E = \Delta N\ \theta_s = 0{\cdot}1$.

The accompanying table summarises the results for different values of the parameters $\Delta E_K/\Delta E$ and $\epsilon$, and

$$\Delta\theta_l{}^* = \frac{0{\cdot}2\ (0{\cdot}5 - 0{\cdot}7)}{0{\cdot}333 + 0{\cdot}2} = -0{\cdot}075$$

$$\Delta\theta_l = \frac{1}{0{\cdot}33}(0{\cdot}1 - \Delta E_K);\ \Delta N\,(\theta_l - \Delta\theta_l{}^*) = 0{\cdot}125.$$

NUMERICAL EXAMPLE GIVING:

$\lambda = \dfrac{K_K\,r_K}{K_l\,r_l}$ for $N_l = N_K = \dfrac{M}{3}$, $\theta_l = 0{\cdot}7$, $\theta_K = \theta_s = 0{\cdot}5$, $\theta_o = 0{\cdot}3$

(Equation 23)

$\Delta N = 0{\cdot}2\ M$ and $\Delta E = \Delta N\ \theta_s = 0{\cdot}1$ and $\Delta E_K$ variable.

| $\Delta E_K/\Delta E =$ | 0 | 0·1 | 0·5 | 1·0 |
|---|---|---|---|---|
| $\Delta E_K$ = | 0 | 0·01 | 0·05 | 0·1 |
| $\Delta\theta_l = \dfrac{\Delta E - \Delta E_K}{\Delta N_l}$ | 0·3 | 0·27 | 0·15 | 0 |
| $N_l\,(\Delta\theta_l{}^* - \Delta\theta_l)$ | −0·125 | −0·115 | −0·075 | −0·025 |
| [. . .] | 0 | 0·01 | 0·05 | 0·10 |
| $\lambda_{max}$ for $\epsilon = 0{\cdot}2$ | 1 | 1·25 | 2·25 | 3.50 |
| $\lambda_{max}$ for $\epsilon = 0{\cdot}5$ | 1 | 1.1 | 1.5 | 2·0 |

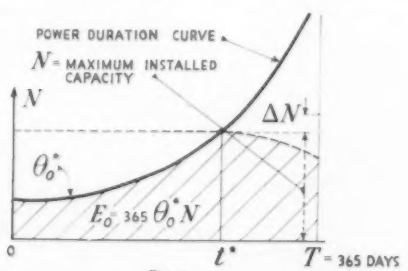



Fig. 8

It is obvious that the higher the running expenses $k_{el}$ are, the lower will be the coefficient $\epsilon$ and therefore the higher the permissible maximum of $\lambda$. In countries where coal is expensive, additional hydro-power capacity is a definite asset, especially when by increasing the hydro capacity from $N$ to $N + \Delta N$ additional hydraulic energy can be obtained. This is the case mainly on rivers where the yearly run-off exceeds the water volume used for power generation with installed capacity $N_K$ (run-of-river stations).

**Summary and Conclusions**

Methods used by system-planning engineers depend on the particular problem with which they are faced. Short-period planning of systems with combined steam and hydro power is based on the calculus of variations or on a practical application of the same basic idea using electronic calculating machines. Long-period planning will be based on statistical methods and interpretation of hydrological data.

The planning of expanding systems should be based on methods specifically developed for that purpose. Any prediction on costs and prices or market prices in the future—say four to five years—is somewhat uncertain. A method that allows easy discussion when basic parameters, like prices, vary, is to be favoured. It is suggested that a method based on the idea of the "simple mathematical model" may be helpful at a first stage of the enquiry. The simple mathematical model may be very useful[20] later, when programming a more detailed enquiry for the calculating machine.

Capacities, energies and prices in an electric system with many components can be interpreted by simple equations or diagrams. These have to be handled by the method in such a way that the discussion of economic advantages becomes possible. Introduction of convenient—dimensionless—parameters may be helpful.

The method developed here was first thought of for dealing with the economics of pumped storage[15, 17]. Its versatility when discussing other problems was shown in a subsequent paper[16].

This final paper is intended to base the method on a broader approach. A whole theory could be developed now by systematically rewriting all the preceding papers[13-17] as an integral part of this method.

Hydro power is one of the major utilities to be gained from water. Others are flood control, irrigation, navigation, etc. These broader aspects of the economics of water utilities have been dealt with mainly by American authors, a few of whom are mentioned in the Bibliography[18, 19, 20].

Planning of electric systems is occasionally being taught at some universities. Few textbooks[21] are available. The time is now approaching when the whole subject could be dealt with as a practical example for modern economic planning.

BIBLIOGRAPHY


1. CYPSER, R. J., "Computer Search for Economical Operation of a Hydrothermal Electric System," *A.I.E.E. Transactions*, Vol. 73, pt. III-B, 1954, pp. 1260-1267.
2. RICARD, J., "The Determination of Optimum Operating Schedule for Interconnected Hydro and Thermal Stations," *Revue Générale de l'Electricité*, Paris, France, September 1940, pp. 167-181.
3. CHANDLER, W. G., DANDENO, P. L., GLIMM, A. F., and KIRCHMAYER, "Short-Range Economic Operation of a Combined Thermal and Hydro-Electric Power System," *A.I.E.E. Transactions*, Vol. 72, pt. III, October 1953, pp. 1057-1065.
4. CAREY, J. J., "Short-Range Load Allocation in Hydro-Thermal Electric Systems," *A.I.E.E. Transactions*, Vol. 73, pt. III-B, 1954, pp. 1105-1111.
5. DEGUISE, I., MACFARLANE, N. F., KING, D., LAWSON, F. C., and NEVISON, R. D. "Various Means of Securing Maximum Output of Existing Hydro-Electric Facilities," World Power Conference, Madrid, June 1960, Paper II.B/4.
6. ARISMUNANDAR, R. A., "General Equations of Short-Range Optimisation of a Combined Hydro-Thermal Electric System," M.A.Sc. Thesis. University of British Columbia, Vancouver, B.C., March 1960.


*(Continued on page 157)*

*Fig. 15. Premadio station surface buildings and switchyard*

# The Valtellina Development

A development using the headwaters of the River Adda in the Italian Alps has been replanned for an ultimate output of 1,500 GWh per annum. In this article we describe Premadio station

PART TWO

THE decision to place Premadio station underground was made for purely economic reasons. At the alternative surface site the station would have had to have been built on a deposit of detritus, and it would have been difficult and expensive to secure the foundations for the generating sets. Furthermore, the penstocks would have been unduly long, and the increased distance between the station and the surge chambers would have impaired the regulation of the turbines.

The station is located in the schist at the foot of Mount Scala, and has been carried only far enough into the mountain to obtain an adequate cover of sound rock, to ensure satisfactory governing, and to enable the access tunnel from Premadio village to be cut at a reasonable gradient. It was necessary also to avoid intersecting certain pervious fault zones communicating with underground thermal springs.

A section and plan of Premadio station are given in Fig. 17, and a view of the machine hall is reproduced in Fig. 16. The cavern is horseshoe shaped and without its lining is 33·2 m wide and 30·5 m high. In its present first stage it is 81·7 m long and has involved the removal of 68,000 m³ of rock. When the second stage is constructed the excavation will be carried to a total length (unlined) of 156·2 m.

The concrete lining is 1·8 m thick at the crown of the arch and 3·5 m thick at the base, and required 18,000 m³ of concrete. The lining was placed before the main body of the rock in the machine hall was broken out, and was cast in sections, each section forming a ring 4 m long. At the roof of the arch small prefabricated concrete blocks were used, secured by high-quality cement mortar.

Within this cavern the machine hall, transformer cubicles and other chambers have been divided off by walls calling for the placing of a further 11,000 m³ of concrete, much of it reinforced. The machine hall, in particular, is bounded by pillars supporting the crane runways and is surmounted by a false roof

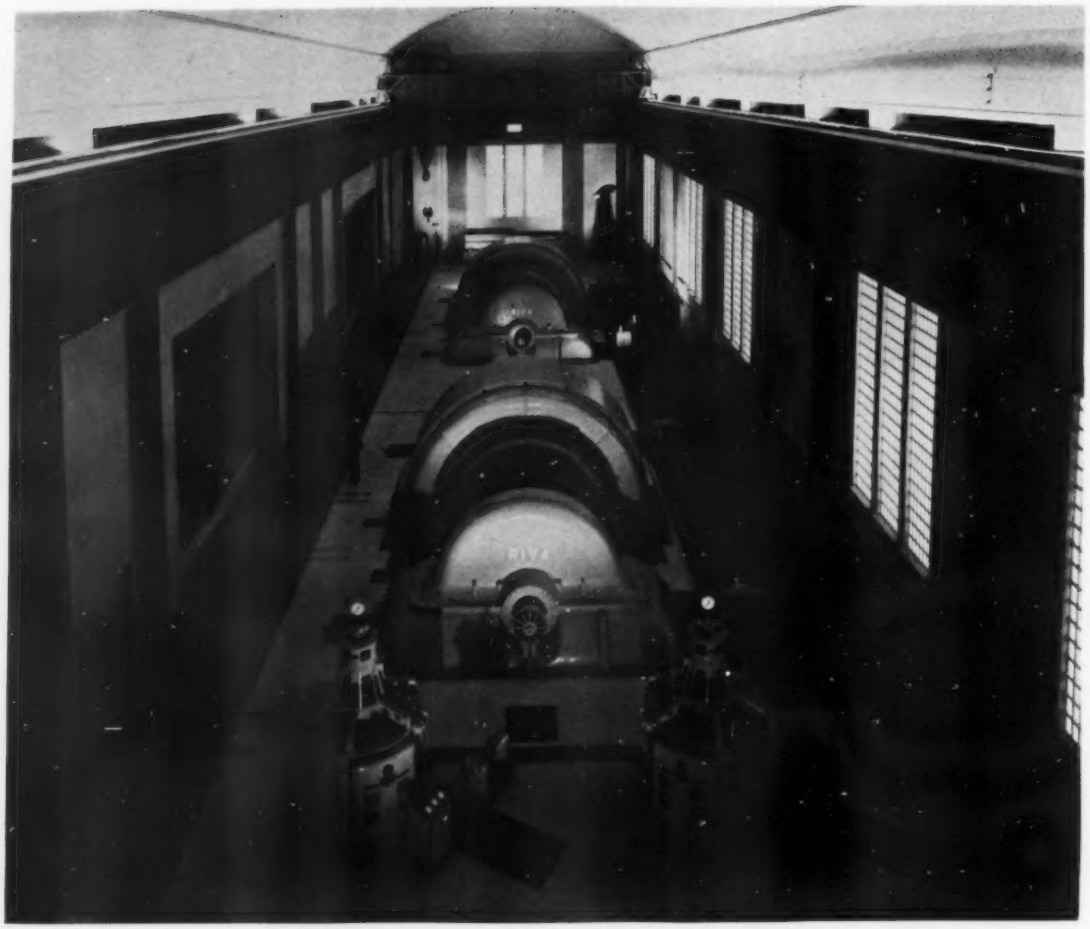


*Fig. 16. The underground machine hall of Premadio station*

resting on hard-rubber anti-vibration mountings, the finished dimensions of the hall being 73·6 m long, 16·2 m wide and 18 m high.

The generating sets, which are horizontal twin Pelton units, are placed side by side with their axes in line, and occupy two bays of the hall, the third and remaining bay being an assembly area. Between the second main set and the assembly area are two 1,300-kW vertical Pelton auxiliary sets. When the second stage of the station is built it will be disposed on the other side of the assembly area, which will thus be roughly central in the final layout.

Two 200-ton cranes serve the machine hall.

The access tunnel, which emerges into the station opposite to the assembly area, is 350 m long and descends from the portal at a gradient of 1 in 9. It has a concrete-lined arched section divided by an upper floor into an upper and a lower gallery; the lower gallery has tiled walls and a paved floor and forms the access tunnel proper, whereas the upper gallery forms a cable passage.

The four discharge tunnels from the turbines converge to a free-flow tailrace tunnel 715 m long and 14 m² in section. A short distance from the station the tunnel section becomes rectangular to accommodate a measuring weir, access to the weir being gained through a passage leading from the access tunnel. At the discharge-tunnel outlet the flow can either pass through a stilling basin to discharge into the Viola or it can be directed into the supply tunnel for Grosio station. The arrangement of the tunnels and surface buildings is seen in Fig. 18.

**Mechanical and Electrical Equipment**

The two generating sets are horizontal single-jet double-wheel machines each rated at 75 MW when running at 300 r.p.m. under a maximum head of 708 m. At this rating the discharge of each machine is 13 m³/sec. The nozzles are of the straight-flow type, and the two nozzles of each machine are controlled in parallel by a common governor unit. A load limiter on this unit controls the output of the set as a whole, but in addition each nozzle is provided with its own load limiter for individual control if desired. Also, a separate rotary valve controls the water supply to each nozzle so that the generating set can run on a single wheel when required.

Lubrication of the bearings is effected by gravity from a tank about 15 m above the level of the machine-hall floor. Alternator cooling is on closed circuit, the cooling water also being held in an overhead tank.

Each alternator is connected solidly to its own 75-MVA, 10/245-kV transformer, making an integral

generator-transformer unit. Each transformer is in a chamber in the side of the machine hall immediately alongside the alternator it serves.

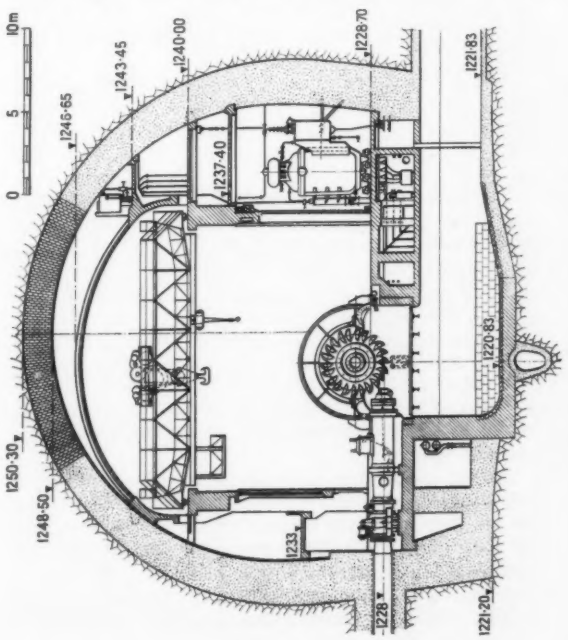
Stage two of the station will contain three identical generator-transformer units, bringing the total capacity of Premadio station to 375 MW.

From the transformers the power is taken to an outdoor switchyard by means of oil-filled cables laid in the cable gallery forming the upper part of the access tunnel. This gallery is 330 m long, the access tunnel itself passing underneath the switchyard to its portal 20 m farther on. There is a difference of level between the two ends of the cables of 50 m, and the lower sections of the cables are reinforced to withstand the oil pressure.

The outdoor switchyard is of the single-busbar type. Each generating unit is controlled by a minimum-oil-type circuit breaker of 4,000-MVA rupturing capacity, and two transmission lines to Milan are served by 5,000-MVA air-blast circuit breakers. The various lines in the switchyard are of aluminium and are held by compression-type clamps. A system of concrete-lined passageways below the surface of the switchyard accommodates the control cables and compressed-air piping.

**Auxiliary Services**

The electrical circuit serving the auxiliaries is kept completely separate from the main high-voltage system, so that the auxiliaries will be unaffected by any disturbance in the main network. As already mentioned, auxiliary power is provided by two 1,300-kW vertical generating sets. These generate at 10 kV, and are connected to 1,300-kVA three-winding transformers furnishing supplies at 23 kV and 220 V. The 23-kV system connects the auxiliary systems of all the power stations in Valtellina and also provides the local supply for the valley. Within Premadio station the supply is stepped down to 125 and 230 V for the various auxiliaries. A 130/23-kV regulating transformer has also been installed to



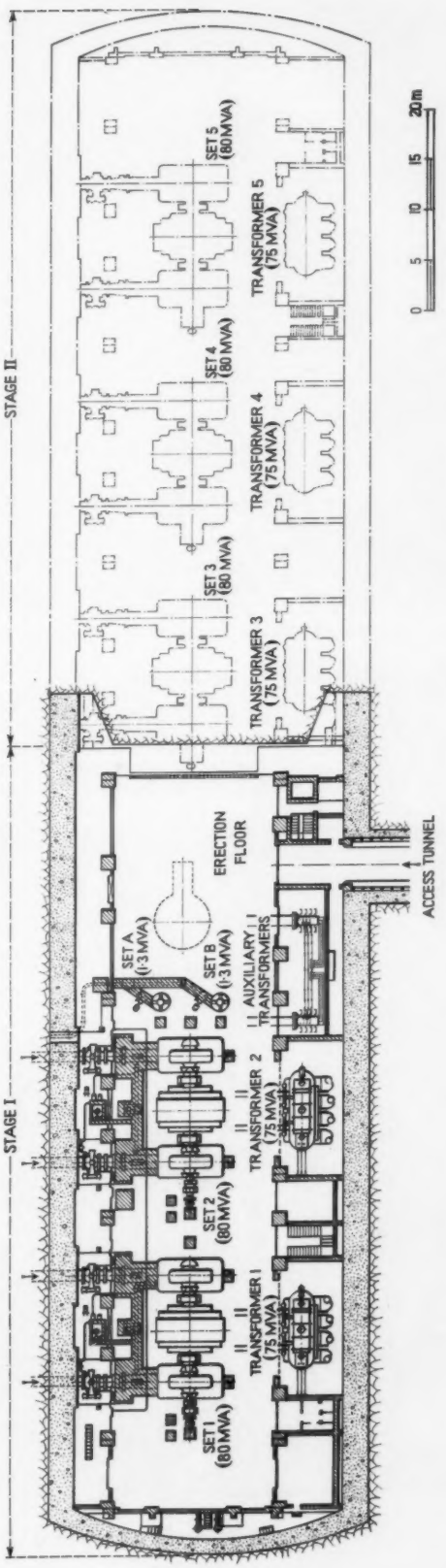




*Fig. 17. Plan and enlarged section of Premadio machine hall, showing the projected Stage II in outline*

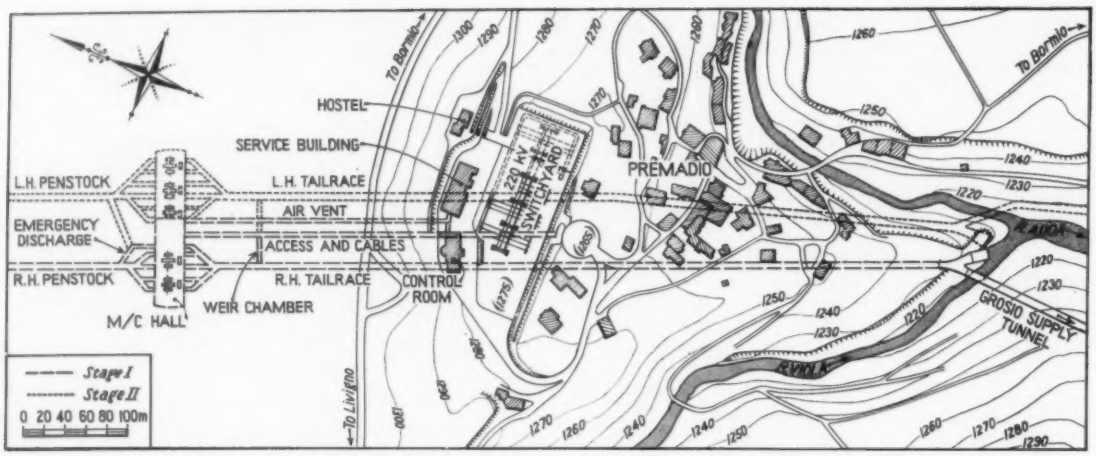



*Fig. 18. General plan of Premadio station, including surface buildings and tunnels*

enable the 23-kV system and the station auxiliaries to be fed from a 130/kV system.

Fire protection has received particular attention. The transformers are protected by water sprays fed from a chamber cut in the side of the penstock tunnel 90 m above the station floor, and the generators are provided with $CO_2$ protection.

**Surface Buildings and Control Room**

The surface buildings associated with Premadio station overlook the switchyard and are divided into three blocks. In the western block are the control room, a lounge, and the living apartments for the station officers. A shaft descends from this block to the access tunnel, and the various control cables from the station and to the switchyard come together in a chamber below the control room.

In the centre block are changing rooms for the operatives, a 23-kV substation for the local network, electrical equipment to supply the aerial ropeway, and the station battery. The eastern block is devoted to offices and stores and also contains a service bay for the circuit breakers. On the roof of this building are the oil tanks for the 220-kV oil-filled cables. Living accommodation for five operatives is provided in a separate building.

The control room overlooks the outdoor switchyard, and on the side facing the switchyard is a vertical board on which are mounted the recording instruments, voltage regulators, protective relays and alarms for the main generators and for the 220-kV transmission lines. In front of this board is a control desk carrying the indicating instruments, controls, and a schematic diagram showing the positions of all circuit breakers and isolators. Against the opposite wall is a vertical control board for the auxiliary sets and for the 23-kV system.

The 220-kV lines are protected by selective distance relays, which, in conjunction with a single-phase high-speed automatic reclosing feature on the circuit breakers, can clear an arc on the line in 0·08–0·10 sec.

Premadio station is designed for full automatic operation from the control room except for a few movements concerned with the lubrication, which are carried out manually. Starting and stopping are completed in four stages, each of which can be controlled independently, viz.: (a) lubricating-oil and regulator-oil pressures at working values, (b) rotary valves open, (c) machine at full speed and excited, and (d) machine paralleled. Starting from the valves-closed position to the point at which the machine is ready to be synchronised can be accomplished in 3 min 15 sec.

Safety under automatic operation is ensured by a full range of electrical protective devices, which can be divided into three classes: (a) those which merely give an alarm; (b) those guarding against external faults, which disconnect the machine but leave it running; and (c) those guarding against internal faults, which disconnect the machine and shut it

*Fig. 19. Main sets in course of erection*

*Fig. 20. Premadio machine hall under construction*

down. In addition, an alarm board in the machine hall indicates any abnormality in the behaviour of the oil, water or air circuits of the turbines and alternators; these indications are repeated in the control room.

**Transmission Lines**

The two 220-kV lines to Milan—a distance of 175 km—are carried on a series of double-circuit towers placed at intervals of about 400 m, the total number of towers being 438. ACSR conductors of 508·9 mm² section are used, carried on porcelain insulators, the suspension strings consisting of 16 insulators in the plain and 17 in the mountains, and the anchoring strings in both cases having two more insulators. Steel earthing wires are provided, of 11·5 mm diameter in the plain and 12·5 mm in the mountains. The highest point of the line is between Valtellina and Val Camonica and is at an elevation 1,869 m. Each line can transmit a load of 180 MW with a loss of 4%.

**Contractors and Manufacturers**

The civil-engineering contractors responsible for the construction of Premadio station were the Società Italiana per Condotte d'Acqua, Rome. The following is a list of the manufacturers of the major items of equipment:—

*Penstock and Butterfly Valves*
Soc. Nazionale delle Officine di Savigliano, Turin.

*Main Turbines and Valves*
Costruzioni Meccaniche Riva, Milan.

*Main Generators*
Compagnia Generale di Elettricità, Milan.

*Auxiliary Turbines*
Costruzioni Meccaniche Riva, Milan.

*Auxiliary Generators*
Compagnia Generale di Elettricità, Milan.

*Cranes*
Soc. Gentili & Brighi, Milan.

*Station Pumps*
Costruzioni Meccaniche Riva, Milan.
Soc. Ercole Marelli, Milan.
Sesto S. Giovanni.

*Main Transformers*
Soc. Ercole Marelli, Milan.
Sesto S. Giovanni.

*Auxiliary Transformers*
Tecnomasio Italiano Brown Boveri, Milan.

*220 kV Oil-filled Cables*
Soc. p.a. Pirelli, Milan.

*Other Cables*
Various suppliers.

*Air-Blast and Minimum-Oil Circuit Breakers*
Tecnomasio Italiano Brown Boveri, Milan.

*Switchyard Insulators*
Ceramica Italiana, Laveno.

*Switchyard Steelwork and Stringing Conductors*
S. A. Elettrificazione, Milan.

*Line Insulators*
Ufficio Vendita Isolatori, Milan.

*Line Fittings*
Salvi, Milan.

*Line Conductors*
Soc. Alluminio, Milan.

*(To be continued)*

# Advances in Low-Head Machines

New possibilities in the development of low heads, whether for run-of-river or for tidal plants, are opened up by the advent of the large axial-flow bulb-type machine. In this final article an account is given of some of the numerous tests carried out on certain of the large bulb-type sets already described

By S. CASACCI

PART THREE

**Transitory Phenomena during Unloading**

THE behaviour of sets not intended for frequency regulation will now be examined in greater detail. For such machines a study of the phenomena arising when the load is disconnected is of great importance. Although the overspeed of normal Kaplan turbines is relatively small, that of submerged machines attains much higher values because of the short runaway time. These abrupt speed variations give rise to transitory phenomena which can be very violent. For such machines these are frequent occurrences, which must not incur wear or undue fatigue. The Cambeyrac set, the runaway time of which is about one second, will be taken as an example.

The curves in Fig. 16 refer to the rejection of a load of 2,600 kW under a head of 11 m. Curves $P_1$, $P_2$, $P_3$ record the indications of piezometers placed respectively downstream of the runner, between the runner and the distributor, and upstream of the distributor. These pressures are taken on the horizontal plane passing through the centreline of the machine. The guide vanes close in 3·5 sec after the load is switched off; they reopen at 4·5 sec and then reclose. The records show that the changes in conditions are abrupt and important. The variation in speed of rotation depends essentially on the instantaneous hydraulic load on the runner. Before load rejection the runner blades and the guide vanes are in step, but after load rejection this synchronism is destroyed, partly because of the difference in the speeds of movement of the blades and the vanes and partly because of the variations in the speed of the set and in the head acting on it.

The turbine efficiency and the power transmitted by the water to the runner diminish from the commencement of closure. As long as this power is positive the machine accelerates, but when the speed reaches its maximum the power supplied to the wheel by the water is nil. This maximum speed corresponds to a small opening of the guide vanes and a large inclination of the runner blades—a condition widely out of step. When the speed decreases, the runner returns energy to the water; it behaves as a reversed pump and accelerates the water in the normal direction of flow. The flow through the runner tends to become stronger than that through the distributor; the pressure between the distributor and the runner becomes lower than that below the runner, and the hydraulic pressure reverses. The pressure between the distributor and the runner rapidly rises as soon as the guide vanes open, and tends gradually towards the pressure corresponding to no-load running. To obtain suitable manoeuvring characteristics the fall in speed can be slower, and the hydraulic load on the runner when functioning as a reversed pump is less, but the time occupied by this phase is longer. The pressure above the distributor gradually approaches that corresponding to no-load running.

The pressure regime during closure depends largely on the size of the load rejected. Fig. 17 relates to the rejection of a load of 4,000 kW under a head of 10·55 m. Curves $P_1$, $P_2$, $P_3$, corresponding to those in Fig. 16, show that the same changes in regime appear as in the previous example. These phenomena, which can be very violent in some cases, depend on numerous factors which are themselves functions of the service conditions, but they can always be avoided by taking special measures.

In normal vertical Kaplan machines the same phenomena appear, but they are usually less dangerous (as regards the unwatering of the runner). Figs. 18 and 19 relate to an emergency closure of one of these turbines. Curves 1–7 show respectively, as a function of time: speed, guide-vane opening, runner-blade angle, pressure between guide vanes and runner, force required to operate the blades, draft-tube pressure, and operating head. The variations in pressure between the guide vanes and runner (curve *2*) and the head (curve *7*) show that the runner acts as a pump during deceleration of the machine. It tends to form a vacuum in the region between the guide vanes and the runner, and the extent of the vacuum obviously depends on the amount of entrained air. The partial unwatering of the runner produces pressure pulsations in the draft tube (curve *6*) and fluctuations in the control force required on the blades. Although it would be preferable to eliminate them, these pulsations do not present any great danger to vertical Kaplan machines. For axial sets, however, a partial unwatering of the upper part of the runner could be very dangerous, as the runner could impose alternating bending moments on the shaft, and heavy pulsating forces could be brought to bear on the blades. Partial unwatering must therefore be avoided at all costs, and special measures are taken to accomplish this.

**Measurement of Control Forces**

The order of the forces required to operate the guides vanes of the distributor and the blades of the runner determines the design of these movable vanes. For obvious economic reasons the dimen-

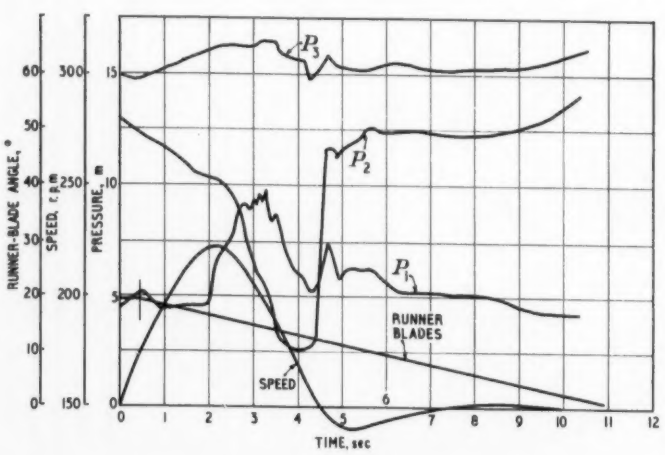



*Fig. 16. Rejection of 2,600 kW under 11 m head (Cambeyrac)*

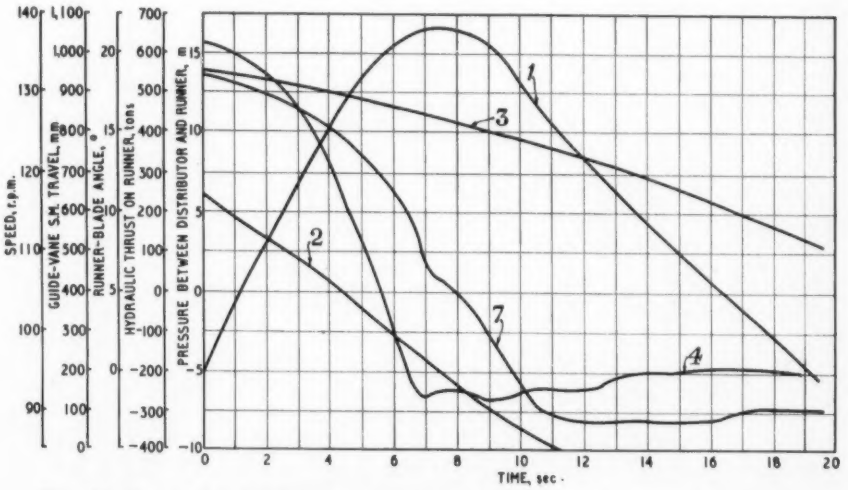



*Fig. 18. Rejection of 35,000 kW under 17·72 m head for Kaplan turbine*

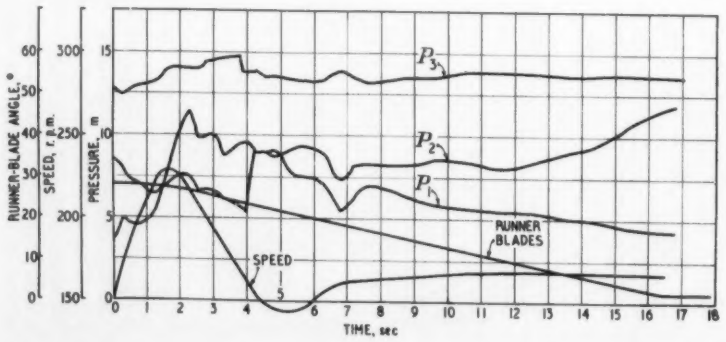



*Fig. 17. Rejection of 4,000 kW under 10·55 m head (Cambeyrac)*

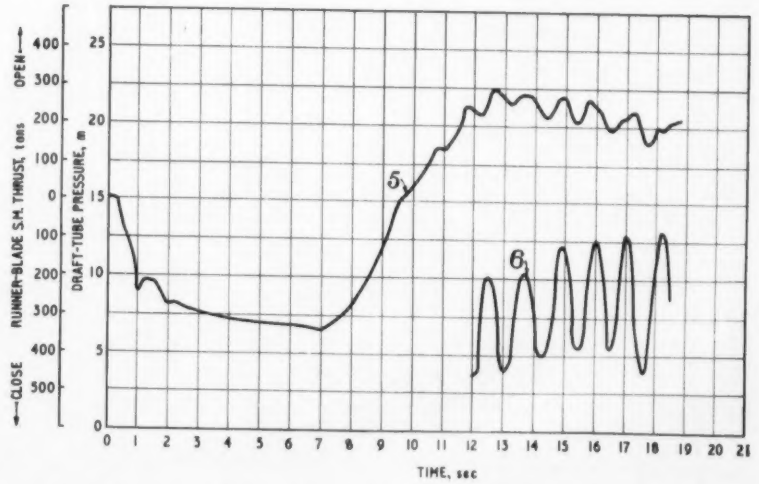
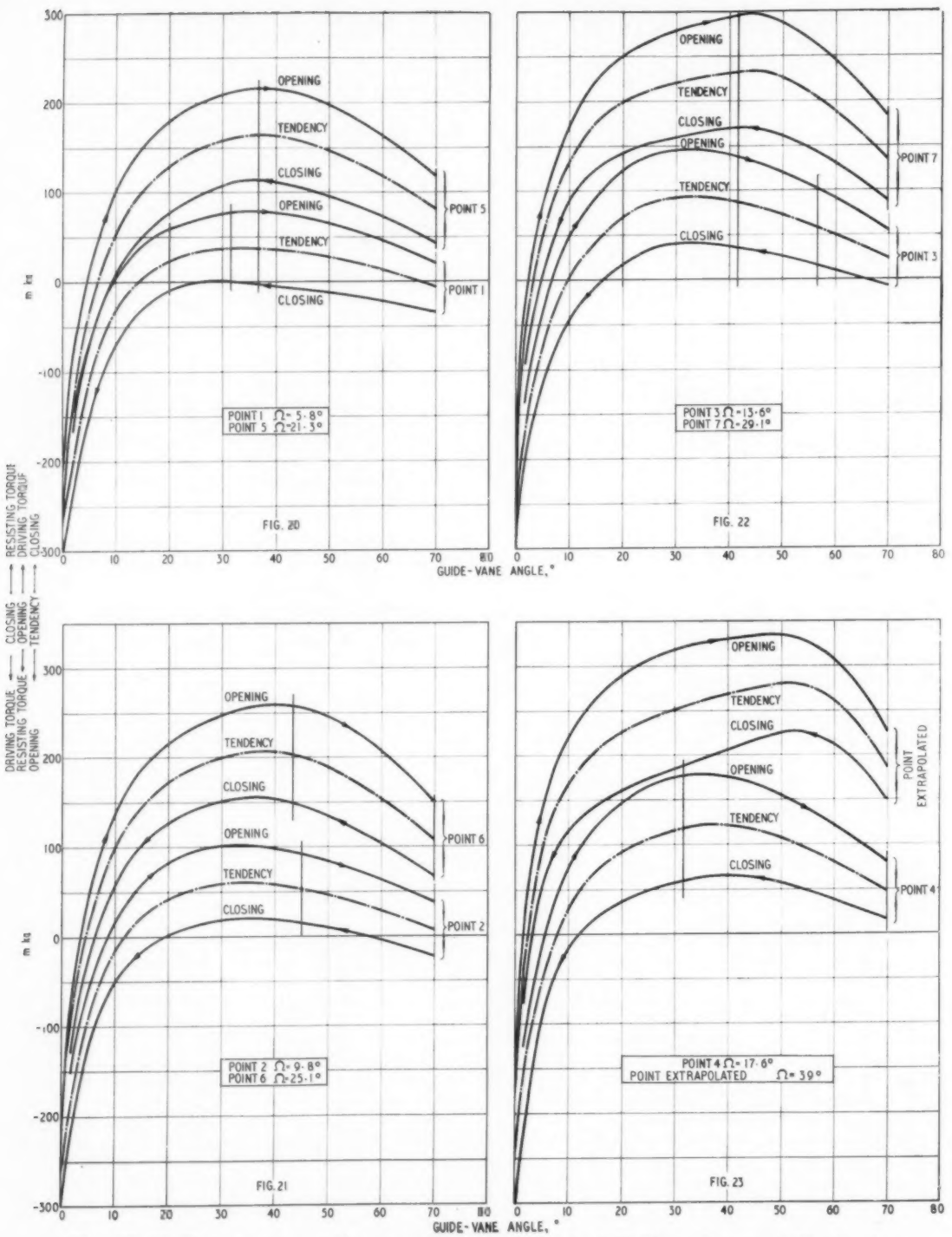



*Fig. 19. Rejection of 35,000 kW under 17·72 m head for Kaplan turbine*




*Figs. 20–23. Torques on a guide vane under a test head of 11·65 m (Beaumont-Monteux)*

sions of the conical distributor used for axial turbines should be the minimum compatible with good performance. The overall size of the distributor, in fact, influences not only the cost of the machine itself but also the centre distance between machines. A reduction in dimensions necessitates acute angles of inflow and of flow past the cones, and affects the shape of the hydraulic circuit, with the result that the forces necessary to operate the guide canes cannot be determined by calculation and must be found by complete tests on models and on prototype machines.

The determination of the forces required to oper-

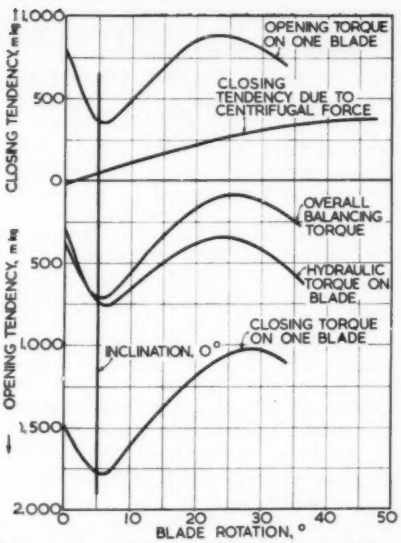

CLOSING TENDENCY, m kg
OPENING TENDENCY, m kg
OPENING TORQUE ON ONE BLADE
CLOSING TENDENCY DUE TO CENTRIFUGAL FORCE
OVERALL BALANCING TORQUE
HYDRAULIC TORQUE ON BLADE
CLOSING TORQUE ON ONE BLADE
INCLINATION, 0°
BLADE ROTATION, °

*Fig. 24. Cambeyrac, direct-turbine phase,* h=*10·75 m. Torque on runner blades during synchronised runner-blade and guide-vane movement*

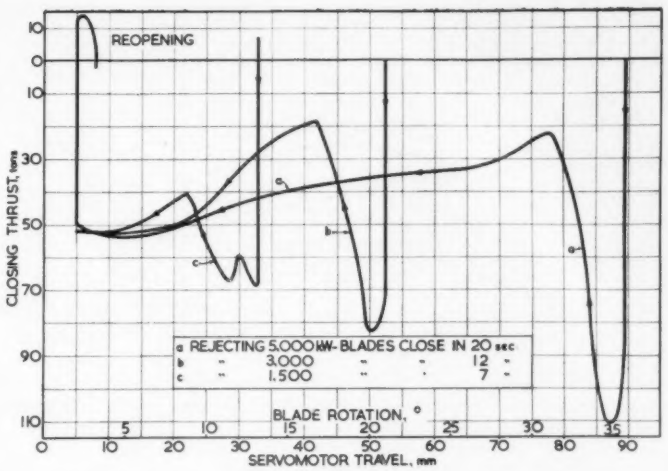

REOPENING
CLOSING THRUST, tons
a REJECTING 5,000 kW- BLADES CLOSE IN 20 sec
b " 3,000 " " 12 "
c " 1,500 " " 7 "
BLADE ROTATION, °
SERVOMOTOR TRAVEL, mm

*Fig. 25. Cambeyrac, direct-turbine phase. Thrust required to close runner blades on rejection of various loads*

ate the runner blades is even more delicate. The forces required for the guide vanes during normal operation, in fact, depend only on the mechanical characteristics and on the discharge. Fluctuations in flow in the guide vanes and below the distributor are slight even during the more abrupt transition phenomena. It is quite different in the case of the runner blades, which during transitory periods are subjected to violent disturbances.

*Measurement of Forces Acting on the Guide Vanes.* Figs. 20 to 23 relate to measurements taken on the Beaumont-Monteux machine described previously. These curves give the overall torque required to open or close a guide vane under a head of 11·65 m. Curves of the hydraulic torque have been inserted on the assumption that mechanical friction is independent of the direction of movement. These results correspond to various positions of the guide vanes relative to the runner blades. The points of measurement have been taken in the region of the best relative setting, as at remote settings cavitation interferes with the results. The extrapolation of these results from the zones of measurement can easily be effected on the basis of the flows measured on the model. The leading details of the distributor are:

10 stationary guide vanes.
20 conical movable guide vanes.
Cone-apex half-angle—65°.
Length of movable vanes—1,030 mm.
Angle of movement—70°.
Eccentricity—1·365.

We have carried out tests on other machines (Cambeyrac, Argentat) with different eccentricities and

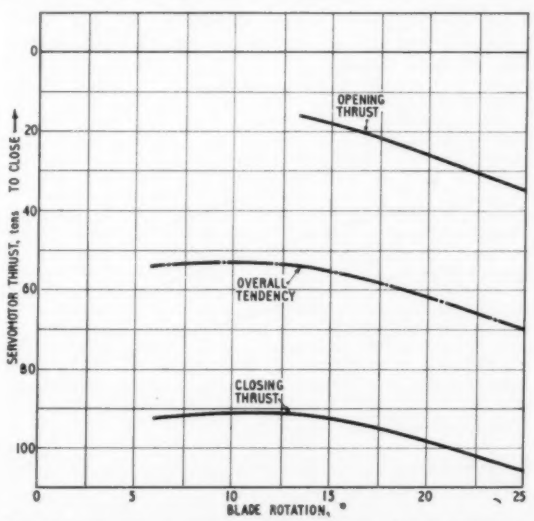



*Fig. 26. Cambeyrac, reversed-turbine phase. Operating thrust on runner blades.* h=*10·35 m. Guide vanes locked open at 92·5°*

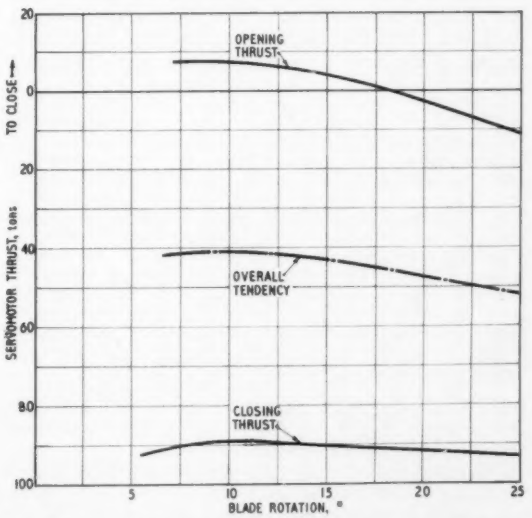



*Fig. 27. Cambeyrac, reversed-turbine phase. Operating thrust on runner blades.* h=*7·35 m. Guide vanes locked open at 92·5°*

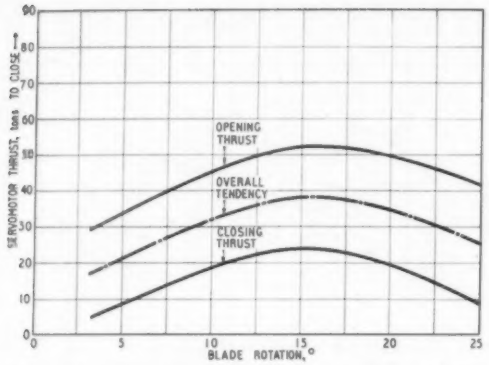



*Fig. 28. Cambeyrac, direct-pumping phase. Operating thrust on runner blades.* h = *1·00 m. Guide vanes locked at 70°*

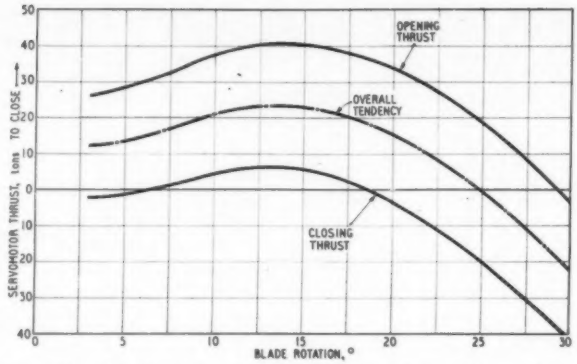



*Fig. 29. Cambeyrac, direct-pumping phase. Operating thrust on runner blades.* h = *2·50 m. Guide vanes locked at 70°*

for both directions of flow. Under conditions of reversed flow the guide vanes have been held securely and no vibration has developed.

*Measurement of Forces Acting on the Runner Blades.* During the tests on the Cambeyrac turbine we measured the forces needed to move the runner blades under the different modes of operation possible with this unit. Figs. 24 and 25 relate to operation as a direct turbine. The curves in Fig. 24 show the variation in torque applied by the servomotor to a blade during the synchronised opening and closing of the runner blades and guide vanes. Fig. 25 shows the variation in thrust required to ensure the closing of the blades upon the rejection of various loads. On removal of the normal rated full load (5,000 kW) the closing force required was 1·5 times the maximum corresponding closure in step with the guide vanes.

Figs. 26 and 27 relate to operation as a reversed turbine. In this condition the runner blades only are moved, the guide vanes being locked full open. The curves show how the operating thrust varies with the head. Maximum thrust is exerted during closure; it varies little with the head and is higher than the corresponding thrust for direct-turbine operation. The hydraulic thrust on the blade decreases as the head rises because the angle of attack of the blades is more suitable. Friction rises slightly with the head.

The control forces measured during pumping are given in Figs. 28 and 29 for direct pumping and in Figs. 30 and 31 for reversed pumping. For these modes of operation only the blades are moved, the guide vanes being locked in positions determined by model tests.

**Characteristics for Good Mechanical Performance**

We have also carried out a series of measurements to ascertain the criteria for good mechanical performance of axial sets, and for this purpose we have conducted comparative tests on normal vertical machines of proved performance and on the Beaumont-Monteux axial machine. The measurements were more particularly concerned with vibrations, or rather with the displacements of the rotor with respect to its bearings. The movements of the shaft were ascertained for different controlled loads and for out-of-step operation during overspeed or underspeed. These measurements have confirmed that axial sets, in spite of the fact that the runner is overhung, display excellent mechanical properties. The tests actually made, indeed, tend to show that movements of the shaft within its bearings are better controlled in axial sets than in vertical ones.

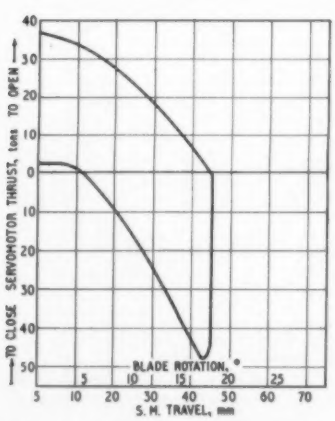



*Fig. 30. Cambeyrac, reversed-pumping phase. Operating thrust on runner blades*

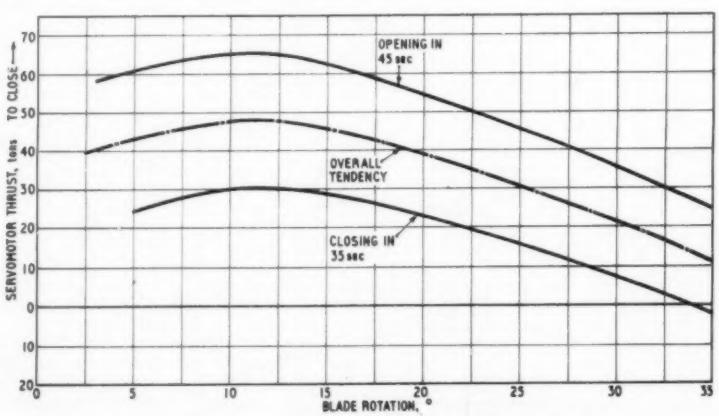



*Fig. 31. Cambeyrac, reversed-pumping phase. Closing tendency on runner blades measured at the servomotor.* h = *0. Guide vanes locked at 75°*

**Conclusions**

The construction of large-capacity axial sets could not be undertaken without a precise knowledge of their hydraulic and mechanical performance. As we explained in our introduction, the development and construction of axial sets are carried out in a series of stages:

Model studies.
Construction of small sets.
Construction of medium-capacity sets.
Examination of the performance of these sets.
Design and execution of large axial sets.

It can be said that the mass of tests, both in the laboratory and on a large scale, and the operating results obtained, show that the technique of bulb-type sets is based on firm scientific and technical foundations, which enable the vast installations in the forthcoming tidal-power plants and in great rivers to be undertaken with confidence.


REFERENCES

1952–53 CARDINAL VON WIDDERN, H., "La Turbine Tubulaire," *Escher-Wyss Bulletin*, T. XXV/XXVI, pp. 22-30.

1952–53 ZINTNER, O .,"Résultats d'Exploitation Obtenus avec les Turbines Tubulaires Système Escher-Wyss," *Escher-Wyss Bulletin*, T. XXV/XXVI, pp. 30-33.

1954 GUIMBAL, J-C., "Les Groupes Immergés de la Centrale de Castet et leur Application aux Équipements pour Basses Chutes de Grande Puissance," *Mémoires de la Société des Ingénieurs Civils de France*, No. 4, pp. 374-384.

1954 CHAMAYOU, H. and GUIMBAL, J., "Les Nouveaux Groupes de la Centrale Prototype de Castet," *La Houille Blanche*, Vol. 9, No. 2, pp. 119-134.

1955 GARIEL, MAURICE, "Developments in Low-Head Hydro-Electric Stations," *Engineering*, Vol. 180, No. 4684, pp. 627-628.

1956 GIBRAT, R. and AUROY, F., "Problèmes Posés par l'Utilisation de l'Énergie des Marées," *Fifth World Power Conference, Vienna*, Vol. 12, Section H, Paper 111 H/22, pp. 4299-4328.

1957 GROS, CH. and GILLET, P., "Evolution dans la Construction des Groupes Hydro-Électriques de Faible Puissance pour l'Équipement des Basses Chutes et ses Répercussions Économiques," *Eleventh Sectional Meeting of the World Power Conference, Belgrade*, Section B4, Paper 49, Vol. VI, pp. 783-796.

1957 KAMMERLOCHER, L., "Groupes Générateurs Hydro-Électriques Immergés Type Bulbe. Développement et Évolution Constructive," *Revue Générale de l'Electricité*, T. 66, No. 7, Juillet, pp. 343-360.

1957 PFENNINGER, A., "L'Évolution de la Construction des Turbines Tubulaires," *Escher-Wyss Bulletin*, T. 3, No. 2, pp., 3, 16.

1958 CASACCI, S. and SAURON, J., "Turbines Axiales en Groupes Bulbes avec Alternateur dans l'Air—Groupes Bulbes de Rivières et Groupes Bulbes de Marémotrice," *Société Hydrotechnique de France*, Vèmes Journées de l'Hydraulique, Aix-en-Provence, June 26-28, Question V, Paper No. 5.

1958 KAMMERLOCHER, L., "Innovations Technologiques dans la Conception des Groupes Bulbes Turbines-Pompes Immergés," *Société Hydrotechnique de France*, Vèmes Journées de l'Hydraulique, Aix-en-Provence, June 26-28, Question V, Paper No. 2.

1958 BOUSSUGES, P., "Turbines Axiales en Puits," *Société Hydrotechnique de France*, Vèmes Journées de l'Hydraulique, Aix-en-Provence, June 26-28, Question V, Paper No. 3.

1958 SERPAUD, J., "Groupe Bulbe à Turbine Axiale et Génératrice Asynchrone Tournant dans l'Huile—Essais sur Modèle et Essais en Vraie Grandeur," *Société Hydrotechnique de France*, Vèmes Journées de l'Hydraulique, Aix-en-Provence, June 26-28, Question V, Paper No. 4.

1958 DANEL, PIERRE, "The Hydraulic Turbine in Evolution," The Institution of Mechanical Engineers, Clayton Lecture, London, December 19.

1960 DANEL, PIERRE, "L'Évolution de l'Équipement des Basses Chutes," *Revue de l'Enseignement Supérieur*, No. 1, January-March, pp. 103-116.

1960 KAMMERLOCHER, L., "La Station Marémotrice Expérimentale de Saint-Malo," *Revue Générale de l'Electricité*, T. 69, No. 5, May, pp. 237-261.


From page 146


7. GORNSTEIN, V. M., and MOSALYEV, A. G., "Methods of Optimum Load Distribution Among the Power Plants of an Electric System," World Power Conference, Madrid, June 1960, Paper II/4.
8. KIRCHMAYER, "Economic Operation of Power Systems," John Wiley, New York, 1958; "Economic Control of Interconnected Systems," John Wiley, New York, 1959.
9. CAVADIAS, G. S., "A Method of Determining the Power Potential of Rivers with Many Reservoirs and Power Plants" (Manuscript), *The Engineering Journal*, Montreal, Canada, April 1959.
10. ROSS, N., BRUDENELL, and GILBREATH, J. H., "Economic Complementary Operation of Hydro Storage and Steam Power in the Integrated T.V.A. System." *A.I.E.E. Transactions*, Vol. 78, pt. III, June 1959, pp. 136-156.
11. VICENS, J. A., "Aplicación del Cálculo Estadístico a la Explotación Coordinada de Sistemas de Centrales Hidroeléctricas," World Power Conference, Madrid, 1960, Paper II.B/15.
12. BECERIL, E., "Un Método Probabilístico para el Estudio de la Regulación interanual de los Rios," World Power Conference, Madrid, 1960, Paper I.A2/9.
13. JAEGER, C., "The Economics of Pumped Storage," WATER POWER, February and March 1957.
14. JAEGER, C., "The Correlation of Nuclear, Thermal, and Pumped-Storage Capacity," WATER POWER, June, July, August 1958.
15. JAEGER, C., "Pumped-Storage Capacity Correlated to Base-Load Electric Energy: A Simplified Mathematical Approach," *Proc. I.C.E.* (London), Paper No. 6384, Vol. 14, November 1959.
16. JAEGER, C., "The Analysis of Large Expanding Electric Systems," *British Power Engineering*, Vol. 1, September and October 1960.
17. JAEGER, C., "Some Problems in Using Pumped Storage for Modern Power Development," *Civil Engineering* (London), January, February, March, April 1960.
18. GOLZE, "Reclamation in the United States," McGraw Hill, Civil Engineering Series, New York, 1952.
19. KRUTILLA, J. V., and ECKSTEIN, O., "Multiple-Purpose River Development. Studies in Applied Economic Analysis," Baltimore, John Hopkins Press, 1958.
20. MAASS, A., and HUFSCHMIDT, M. M., "Report on the Harvard Programme of Research in Water Resources Development," Papers of the Western Resources Conference, 1959, University of Colorado Press, Boulder, 1960. See also:
MAASS and HUFSCHMIDT, "In Search of New Methods of River System Planning," *Journal Boston Soc. Civ. Eng.*, Vol. XLVI, No. 2, April 1959.
21. MUSIL, L., "Praktische Energiewirtschaftslehre," Vienna, 1949.


**Rotary Air Compressors.** An attractively presented catalogue that describes their latest range of Power Vane air compressors has been received from Consolidated Pneumatic Tool Co. Ltd., of 232, Dawes Road, London, S.W.6. A full account is given of the rotary principles on which these compressors are designed, and there are specifications and descriptions of each model, including the Land-Rover-mounted model 125, described in the December 1960 issue of WATER POWER. The machines are stated to include several new features, and all compressors now have electrical starters as a standard fitting.

# Design of Circular Volute Casings

The author applies the law of constant angular momentum in his derivation of a simple method of determining the radii of circular volute casings for turbines and pumps

By A. THIRUVENGADAM*

A SIMPLE relationship between the specified design values of discharge, peripheral component of the velocity and the radius of the runner, and the radius of the circular volute can be derived by substituting the law of constant angular momentum in the discharge equation for a small element of area of the volute, and integrating the resulting equation. The solution can be presented in the form of a graph from which the volute radius can be read off directly without any of the usual trial-and-error procedures. This method eliminates the necessity for the geometrical construction, which is normally an approximation, used to design the circular volute casings of turbines and pumps.

Fig. 1 is an outline diagram of the circular volute casing under consideration. Although the equations are derived for a pump casing they are also valid for turbine casings.

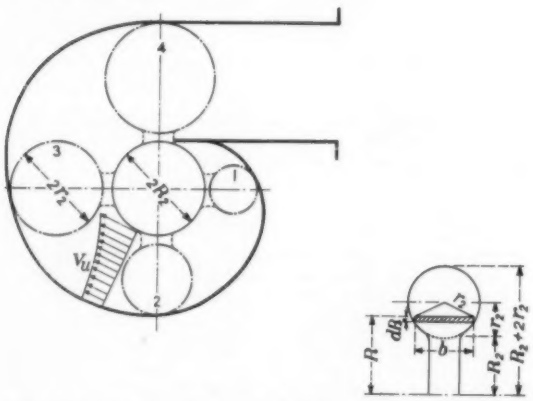



*Fig. 1. Line diagram of the casing under consideration*

When the design of the impeller is finalised the discharge $Q$, the outer radius $R_2$ of the impeller, and the peripheral component $V_{u2}$ of the velocity at the exit of the impeller are known. From these data it is required to determine the radius of the circular volute. If a small element of the area is taken (Fig. 1) then:

$$dQ = b\ dR\ V_u \qquad \ldots (1)$$

where $dQ$ = the discharge through the element
$b$ = the breadth of the element
$dR$ = the thickness of the element.

The law of constant angular momentum is:

$$V_u R = V_{u2} R_2 \qquad \ldots (2)$$

where $V_u$ is the peripheral component of the velocity at a radius $R$.

Again: $$b = 2\sqrt{r_2^2 - (R_2 + r_2 - R)^2} \qquad \ldots (3)$$

where $r_2$ is the radius of the circular volute.

Substituting for $V_u$ and $b$ from equations (2) and (3), equation (1) becomes:

$$dQ = \frac{2V_{u2}R_2}{R}\sqrt{r_2^2 - (R_2 + r_2 - R)^2}\ dR \qquad \ldots (4)$$

The total discharge through the cross section is obtained by the integration of equation (4), thus:

$$Q = \int_{R_2}^{R_2+2r_2} \frac{2V_{u2}R_2}{R}\sqrt{r_2^2 - (R_2 + r_2 - R)^2}\ dR \qquad \ldots (5)$$

$$= A\int_{R_2}^{R_2+2r_2} \frac{1}{R}\sqrt{(B - C^2) + 2CR - R^2}\ dR \qquad \ldots (6)$$

where $2V_{u2}R_2 = A$; $r_2^2 = B$; and $R_2 + r_2 = C$.

This integral is of the form:

$$\int \frac{1}{x}\sqrt{a + bx + cx^2}\ dx$$

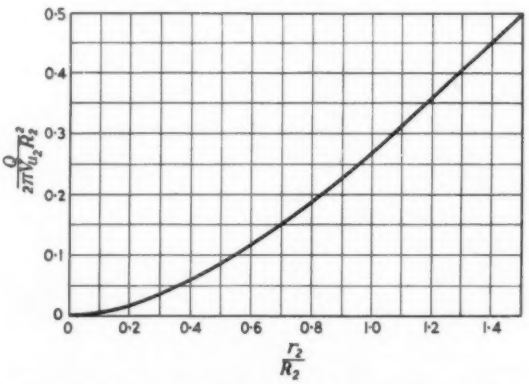



*Fig. 2. Curve for the solution of equation (10) and the determination of the volute radii*

On integration one obtains:

$$I = \left[\sqrt{(B - C^2) + 2CR - R^2}\right]_{R_2}^{R_2+2r_2} + C\left[-\sin^{-1}\left(\frac{2C - 2R}{\sqrt{4B}}\right)\right]_{R_2}^{R_2+2r_2} + \frac{B - C^2}{\sqrt{C^2 - B}}\left[\sin^{-1}\left\{\frac{2CR + 2(B - C^2)}{R\sqrt{4B}}\right\}\right]_{R_2}^{R_2+2r_2} \qquad \ldots (7)$$

After substituting for the limits, for the values of $B$ and $C$ and simplifying, the integral becomes:

$$I = 0 + \pi R_2\left(1 + \frac{r_2}{R_2}\right) - \pi R_2\sqrt{1 + 2\frac{r_2}{R_2}} \qquad \ldots (8)$$

Hence:

$$Q = 2V_{u2}R_2\,\pi R_2\left[1 + \frac{r_2}{R_2} - \sqrt{1 + \frac{2r_2}{R_2}}\right] \qquad \ldots (9)$$

* Senior Research Fellow, Civil and Hydraulic Engineering Section, Indian Institute of Science, Bangalore 12 (India).

i.e., $\frac{Q}{2\pi R^2_2 V_{u2}} = \left(1+\frac{r_2}{R_2}\right) - \sqrt{1+\frac{2r_2}{R_2}}$ ...(10)

Now the right-hand side of equation (10) is a function of $\frac{r_2}{R_2}$, and this function is plotted in Fig. 2 for values of $\frac{r_2}{R_2}$ up to 1·5. From this figure the radius of the circular volute can be easily computed.

**Example of the Method**[1]

It is required to design a circular volute casing for a total discharge of 12·6 cusecs from an impeller of 0·54 ft radius. The peripheral velocity at the exit of the impeller is 21·3 ft/sec.

The casing may be divided into four sections, each of which corresponds to a quarter of the impeller circumference. These sections are labelled 1–4, as shown in Fig. 1, and it is assumed that the casing between each section receives a quarter of the total flow. The quantity $\frac{Q}{2\pi R^2_2 V_{u2}}$ can therefore be calculated for each section, and the corresponding value of $\frac{r_2}{R_2}$ determined from Fig. 2. Thus the radius $r_2$ can be found for each section, as shown in the accompanying table. This radius may be increased to allow for friction losses, using some of the formulae available in literature.

TABLE SHOWING EXAMPLE OF DETERMINATION OF VOLUTE CASING RADII

| Section | Flow | $\frac{Q}{2\pi R_2^2 V_{u_2}}$ | $\frac{r_2}{R_2}$ | $r_2$ |
|---|---|---|---|---|
| | cusecs | | | in |
| 1 | 3·15 | 0·0806 | 0·48 | 3·11 |
| 2 | 6·3 | 0·1615 | 0·73 | 4·72 |
| 3 | 9·45 | 0·2420 | 0·93 | 6·01 |
| 4 | 12·6 | 0·3230 | 1·12 | 7·25 |

**Acknowledgment**

The author is grateful to Professor N. S. Govinda Rao, for encouragement and guidance.

REFERENCES

1. A. DE KOVATS and G. DESMUR. "Pumps, Fans and Compressors," Blackie & Sons Limited, 1958, p. 222.
2. M. NECHLEBA. "Hydraulic Turbines—Their Design and Equipment," Constable & Co. Ltd., 1957, pp. 211–214.

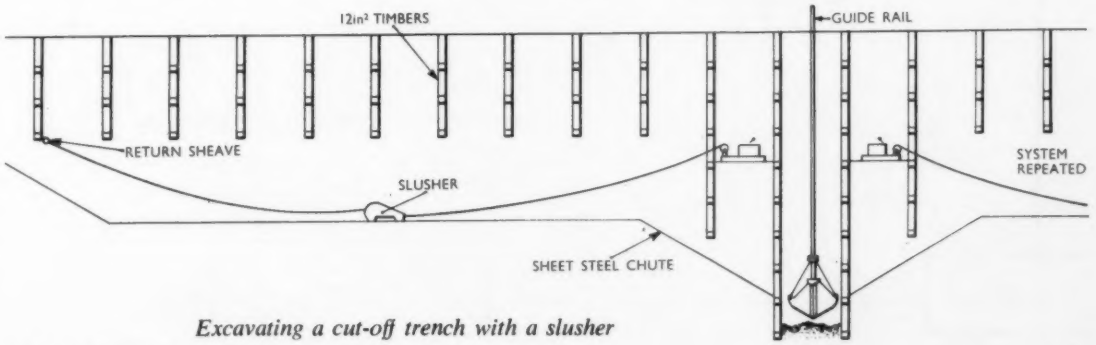
# Improved Method of Cut-off Excavation

An improved system of excavating cut-off trenches in soft ground has been developed by the Thyssen Shaft Sinking Co. Ltd. in conjunction with Michael and Partners Limited of 99 Saltergate, Chesterfield, Derbyshire, England. Whereas narrow, deep cut-off trenches often necessitate excavation by hand, with consequent low productivity, the new method is claimed to have considerably reduced the labour force at the Staunton Harold water-supply-reservoir site in Derbyshire, and to have increased the output to 80 cu yards per man-shift.

The first improvement in the method of excavation of the cut-off was brought about by the replacement of manual labour by a Joy-Sullivan N.221 double-drum slusher, using a scraper bucket that was specially designed for the job.

The first stage of the operation was to sink a shaft midway along the site of the trench, to a depth of about 10 ft in excess of the final trench depth. The cross section of the shaft was 6 ft, which was the width of the trench, by 15 ft. The larger dimension allowed for two bays for the positioning of the slusher haulage, and a central bay for spoil raising by crane and skips. The shaft was timbered, and the slusher scraped spoil into the central bay of the shaft. Slushing had to be stopped periodically to timber the sides of the trench and to lower the slusher haulage as the trench floor became deeper.

The output of the slushers, however, was restricted by the speed of removal and disposal of the spoil, and it was decided that the most promising development would be the substitution of a grab for the skips. Michael and Partners therefore adapted one of their standard 21/17 ft³ capacity self-trimming grabs for




*Excavating a cut-off trench with a slusher*

the purpose. This grab is essentially a digging grab, and it is stated that, owing to the receding radius of its jaws, it tends to pull itself into the stock so that it digs throughout the closing stroke, and lifts a full load every time. The jaws are geared together with double trunnions, and are controlled by twin ropes. The jaws are also bevelled and hard faced so that the grab will cut straight into the ground under its own weight without any added momentum. A spring-loaded guide system was designed and incorporated in the grab to give a lateral variation of 6 in between guide rails. The guide shoes, which are made of high-carbon steel, have a self-feeding profile.

Using this grab with a standard double-drum Smith 21 excavator supplied by Thomas Smith & Sons (Rodley) Ltd., it is now no longer considered necessary to sink a deep shaft at the centre of the cut-off excavation. The method of operation now consists simply of excavating a central sinking bay to a sufficient depth to contain a slusher haulage system mounted above a sheet-steel chute and to proceed from there. Guide rails are fitted to the timbered sides of the sinking bay, and the grab can be dropped straight down to bite into the spoil gathered by the slusher. The grab is able to deepen the sinking bay as the trench becomes deeper.

With this system only 10% of the excavation is done manually. This work is confined to hand-dressing the sides of the trench, timbering, and lowering the slusher haulage and sheet steel chute. The labour force has been reduced from 114 men, using eight cranes and eight hoppits, to the two men who operate the crane and the slusher, and a third man who controls the grab.

# Transmission-Line-Fault Locator

Ferranti Limited, of Ferry Road, Edinburgh, have developed a new line-fault locator, which has been designed for simple operation in manned or unmanned substations. It is primarily intended for use on 132-kV and 275-kV transmission lines but is deemed to be suitable for either higher or lower voltages. The equipment, which uses the normal station-battery d.c. supply, consists of four units designed to fit standard racking. It has been tested under live conditions at Fort Augustus and Clydesmill, in co-operation with

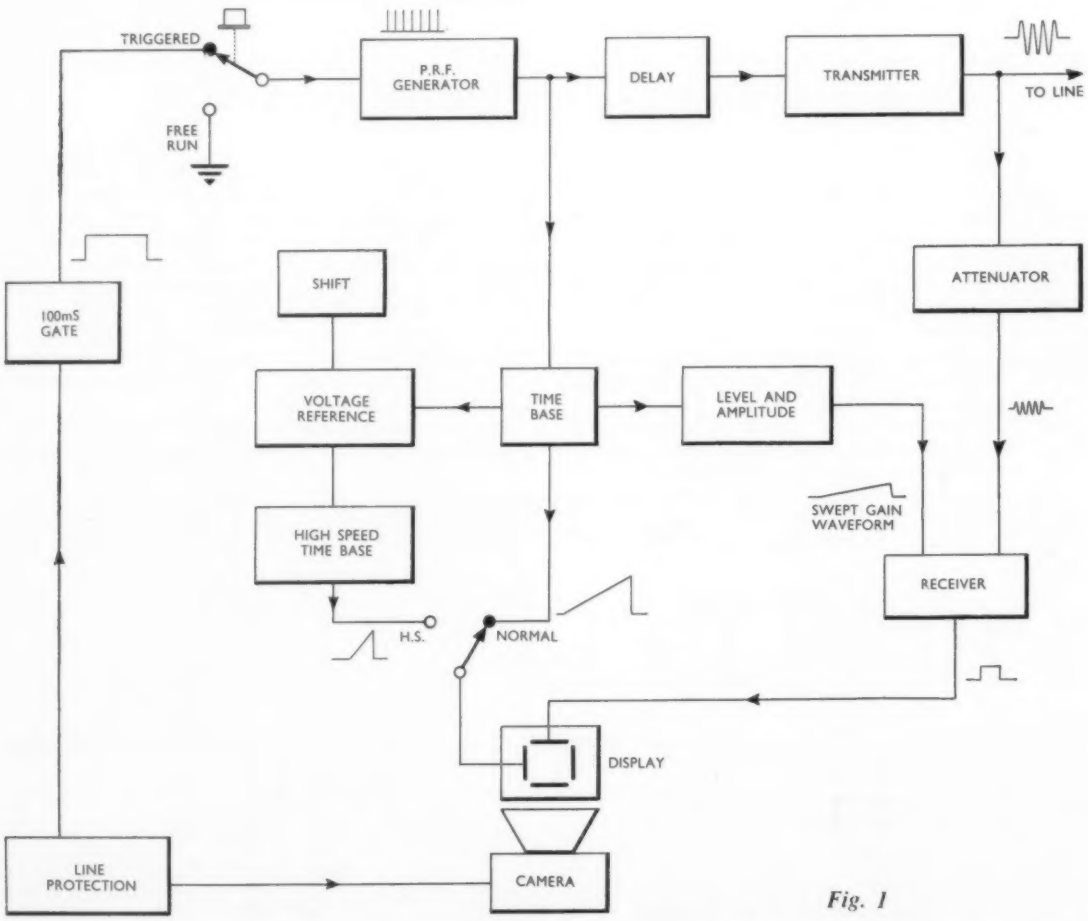



*Fig. 1*

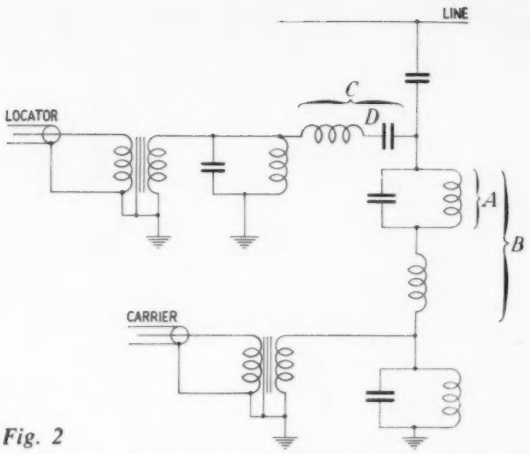



*Fig. 2*

the North of Scotland Hydro-Electric Board and the South of Scotland Electricity Board.

The locator operates on a pulse system, in which reflection occurs from such line discontinuities as arcing faults, icing of conductors and conductor oscillation. The transmitted signal is generated in the locator, and consists of 400-V peak-to-peak pulses, each five microseconds long, at a mean frequency of 1,000 kc.p.s., and spaced at intervals of approximately five milliseconds.

These pulses are coupled to the line, and transmitted along its entire length. Any discontinuity on the line results in a change in the transmission characteristics, and causes a reflection. The reflected pulses are received by the locator and displayed on a cathode-ray tube for either visual observation or automatic photographic recording.

The recording of a fault must be carried out within the time interval between the operation of the first fault relay and the opening of the main circuit breaker on the line. This interval has a duration of about 150 milliseconds, but the actual available recording time is some 20 milliseconds less than this interval owing to the time allowed for the decay of transients, which are caused by the initial striking of the fault arc. The shutter of the recording camera employed has a delay in opening of about 20 milliseconds from the moment of triggering, and thus supplies the required lag before recording the reflected pulses.

Operation of the fault locator is initiated by the

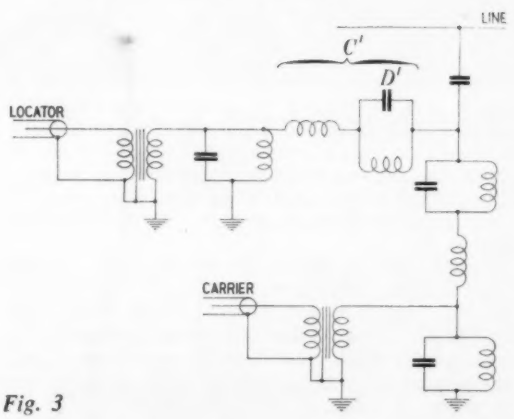



*Fig. 3*

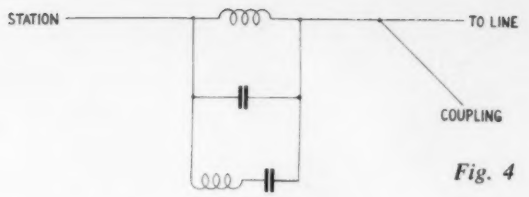



*Fig. 4*

receipt of an impulse from the fault relays in the line protection circuit (see Fig. 1). The camera is triggered and a 120 millisecond gate is produced. The gate causes the pulse-repetition-frequency generator to run for the same period at a frequency of approximately 200 pulses per second. The generator first triggers the time base and then, after a small delay to allow the time base to start, it triggers the transmitter.

The reflected pulses pass through the attenuator to the receiver where they are amplified, detected and finally displayed on the cathode-ray tube.

Throughout the time base sweep, the receiver gain is varied to compensate for line attenuation and so produce a line trace of constant amplitude. This is achieved by means of the level and amplitude circuit, which produces a swept gain waveform that can be varied for any particular line.

A separate high-speed time base is included in the equipment, and this permits more detailed examination of sections of a long line to be carried out. It is set to scan some 15 miles of line, and can be moved to examine any specific section of a long transmission line by means of the shift control, operating through the voltage reference circuit. The main time base can also be preset to make the trace cover distances of from 20 to 100 miles.

The camera employed in conjunction with the locator is a Shackman Autocamera Mk. III, which resets itself automatically after photographing a fault trace. Thus provision is made for the possibility of further faults occurring before the film has been developed and examined.

The type of display used gives a picture of the permanent features of the line, and thus provides a simple basis for range calibration. The accuracy obtainable is stated to be 1% of the length of the line or 3,000 ft, whichever is the greater. The minimum range for fault location is one mile, and the maximum

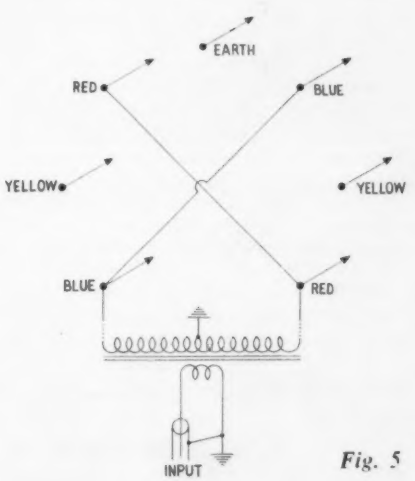



*Fig. 5*

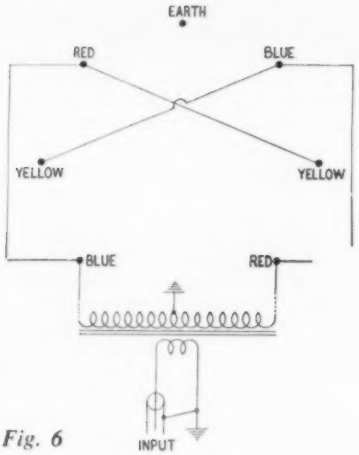



*Fig. 6*

range is between 80 and 100 miles, depending on local line conditions.

**Coupling Systems**

The safest and most reliable method of coupling the locator to a transmission line is through a series capacitor. If there is no existing coupling, then coupling condensers with a series inductor tuned to resonance at one Mc.p.s. may be used in conjunction with an appropriate shunt network designed as a bandpass filter. If coupling capacitors exist for carrier protection circuits, these can also be used to couple in the locator.

Figs. 2 and 3 illustrate two slightly different methods of coupling both the carrier and locator frequencies without mutual interference occurring. In Fig. 2 the filter circuit A is tuned to reject the locator frequency, and the whole circuit B acts as an inductor that is in series resonance with the line coupling capacitor at the carrier frequency. The filter circuit C accepts the locator frequency, and the capacitance of the condenser D is sufficiently low to reject the carrier frequency.

This method cannot be applied at the higher carrier frequencies because the condenser D cannot be made sufficiently small to reject them adequately. In this case the circuit shown in Fig 3 may be employed. Condenser D is replaced by D′, which is tuned to reject the carrier frequency, while the circuit C′ continues to accept the locator frequency. Each of these coupling systems has sufficient bandwidth to cope with the standard carrier frequencies.

It is necessary in all line-coupling systems to prevent radio-frequency power from being fed back into the busbars or transformers at the sending end of the line. The normal procedure is to use a tuned rejector circuit, or "line trap," between the coupling point and the station end of the line. When coupling the locator to the line a rejection circuit is required with two tuning points, one for the carrier frequencies and the other for the locator (see Fig. 4).

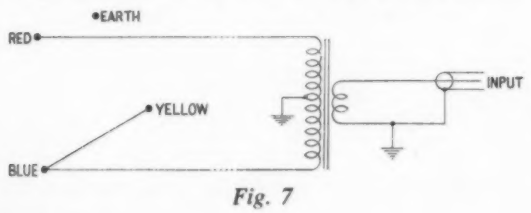



*Fig. 7*

In the case where coupling already exists to two phases out of three in a double-circuit line, the scheme shown in Fig. 5 would normally be utilised. In these circumstances a phase-to-earth fault on the unconnected phases would not be detected. For greater protection the layout shown in Fig. 6 can be used. This arrangement allows all six phases to be monitored without the complications of switching and the provision of separate displays for pairs of phases. Although this circuit does not record shorts between top and bottom phases, such phases are almost invariably accompanied by middle-phase faults, which can be recorded.

On single-circuit lines the problem is much simpler and the coupling illustrated in Fig. 7 could be employed.

## Mapping Instrument

The Vertical Sketchmaster Mk II is a new monocular instrument, produced by Nash and Thompson Limited, of Hook Rise, Tolworth, Surrey, England, and designed primarily for the transfer of information on to maps from single vertical or moderately tilted aerial photographs. It can be used to effect reconciliation between photographs and maps, the scales of which differ within the range 2·5 : 1 and 0·5 : 1. The instrument is stood over the map to be marked up, which is viewed simultaneously with the aerial photograph by means of a semi-silvered mirror. Scale changes and, if necessary, tilt adjustments are made in a direct manner. Lenses and a peep-sight are provided to overcome the difficulties that would otherwise arise when effecting a change of scale.

The Sketchmaster can also be used to compare, and to transfer detail between maps or drawings of different scales. It is a lightweight instrument suitable for use in the office or in camp, and can be supplied with a sturdy transport case.

## A New One-Coat Finish

The bulk of the expense involved in protecting any steel structure from corrosion with a paint is the labour cost. For this reason Camrex Limited have produced a series of paints, which are admittedly more expensive than the normal paints, but are intended to protect iron and steel for considerably longer periods than the usual two to three years. The majority of the paint systems marketed to date are either of the multi-coating type or are paints that never completely dry out. The first type of system suffers from the disadvantage that the structure to be painted may well be out of action for a considerable period of time, to allow for adequate surface preparation plus long drying times between coats. The second type is not always a practical proposition as paints of the non-drying type cannot be used where there is considerable traffic and constant risk of mechanical damage.

A paint that is claimed to obviate both of these disadvantages has been produced by Camrex Limited, Camrex House, Hudson Road, Sunderland, Co. Durham. This product, known as Camrex D-One Kote, is a two-pack paint designed specifically to give a one-coat finish with a coverage of 20 to 25 sq yards per gallon. It is said to give a corrosion-resisting film

# X-ray investigation secures longer life

NOHAB use X-ray investigation in order to get the longest possible life from their turbines. X-ray analysis, by unfailingly revealing all deficiencies in the welds, does not allow any doubtful material to be passed. The control is complemented by ultrasonic examination at other critical points. This extreme care is one of the reasons why NOHAB have obtained so many large orders. FURNAS, Brazil, and BAYGORRIA, Uruguay, are some new NOHAB installations.
You can contact NOHAB regarding both water-power and atomic-power projects.

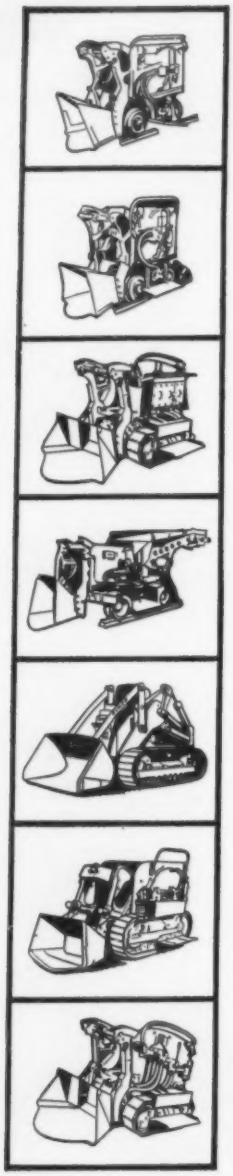
NOHAB

**NYDQVIST & HOLM AB**
**TROLLHÄTTAN SWEDEN**

Cables NOHAB Telex 5284 Phone 180 00

Subsidiary in Canada:
**NOHAB CANADA LTD. Montreal and Toronto**

S SWEDEN



# Wherever the going is tough you'll find an EIMCO

Tough conditions call for tough equipment—Eimco equipment. Whether it is a tunnel to be driven against the clock or a furnace to be repaired in a hurry Eimco loaders speed the job, cut costs and keep on loading no matter what the conditions.

If YOU have a tough job you can't beat an Eimco.

**EIMCO (GREAT BRITAIN) LIMITED**

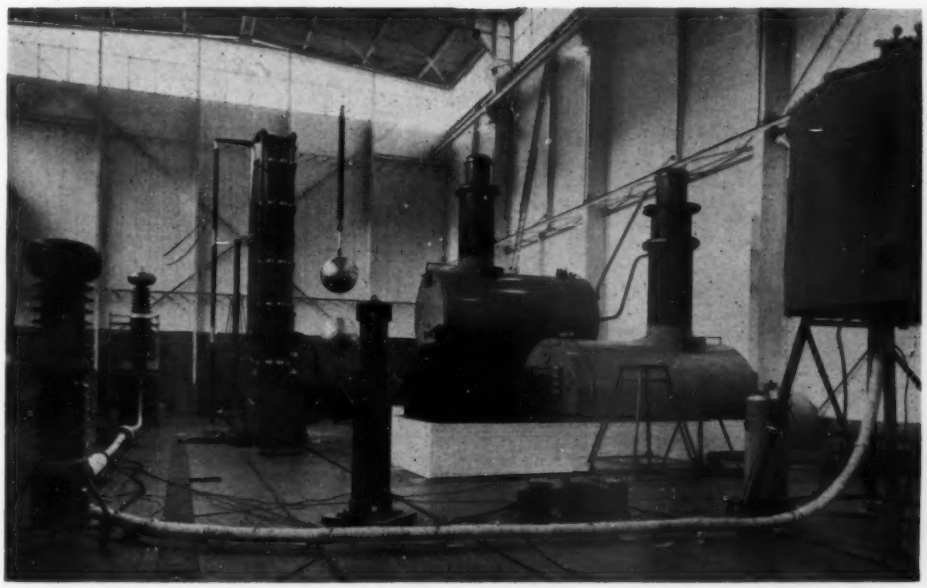
HEAD OFFICE: TEAM VALLEY, GATESHEAD 11, CO. DURHAM. 'PHONE: LOW FELL 7-7241.
LONDON OFFICE: PRINCES HOUSE, PICCADILLY, W.1. 'PHONE: REGENT 2184

P3461

with outstanding toughness and durability with a single application. It is claimed to be impervious to moisture, to have an excellent resistance to oils, to be heat resistant, and, indeed, able to withstand immersion in boiling water.

To apply this coating, the surface requires thorough cleaning, and, ideally, it should be shotblasted. The coating produced will dry in only six hours, although maximum hardness will be attained in 7 to 10 days. This drying or curing will be retarded if the ambient temperature falls below 50°F. Camrex D-One Kote is available in either black or bronze.

# 400-kV Cable Tested in New Laboratory



*Pirelli-General high-voltage testing laboratory at Eastleigh*

The need for the transmission of increasing quantities of electrical power has resulted in a steady increase in the operating voltage of transmission lines throughout the world. This upward trend has so far reached higher values of voltage abroad than it has in the United Kingdom, but the recent proposal by the Central Electricity Generating Board to increase the voltage of existing 275-kV lines to 400 kV will bring the United Kingdom into line with other countries in this field.

In anticipation of the need for cables at this voltage level, Pirelli-General has designed and submitted for approval a complete cable system for operation at 400 kV. The 400-kV cable is a low-pressure oil-filled cable, designed on the same basis as the well-known oil-filled cable system for lower voltages, which has been accepted as standard practice in service in many countries over many years. A complete range of accessories is available for use with the 400-kV cable, and these consist of an outdoor sealing end, an oil-immersed sealing end, which enables the cable to be terminated in the entry chamber of a transformer, a straight-through joint and a stop joint.

The cable is of the single-conductor type with an overall diameter of 4·10 in. A 3-ph circuit comprising three cables of this size laid in the ground side by side, with a spacing of 12 in centres, would have a continuous power-transmission capacity of 528 MVA to 675 MVA over the range of soil thermal resistivity normally encountered. This is equivalent to 710,000–905,000 h.p., and equals the entire output of a large modern generating station.

At the recent opening of the new Pirelli-General High Voltage Cable Testing Laboratory at Eastleigh, Hampshire, England, one of the 400-kV assemblies was tested. Testing was commenced at 1,400 kV, the declared withstand level for the 400-kV cable. After the application of ten negative and ten positive impulses, the voltage was raised in 50-kV steps to 1,600 kV, with the same impulse application at each level. It is stated that no breakdown of the assembly occurred.

The new laboratory building has been fitted with existing equipment, with some additions, and greatly increased working space is now afforded. The provision of adequate floor space and height is particularly important in view of the trends towards higher transmission voltages, and the consequent need for heavier equipment.

The building is divided into two bays, which are both controlled from a central control room. The most important items of test equipment for cable testing and development work are the impulse generator and the HV a.c. testing transformer, and each bay of the new laboratory is equipped with both of these items. The larger bay contains a Micafil impulse

**Floating Docks**
**Ship Lifts**
**Slipways**
**Floating Caissons**
**Floating Crane Pontoons**

Top:
10,000-ton floating dock with ship docked
Centre:
Launch of a floating dock
Bottom:
Floating caisson for a dry dock; 109 ft. long, 17 ft. wide, 45 ft. high
Weight 570 tons.

FRIED. KRUPP MASCHINEN- UND STAHLBAU RHEINHAUSEN

U. K. Agents: J. M. J. Maus Ltd., 35 New Broad Street, London E. C. 2

generator with an open-circuit surge voltage of 2·4 million V and a surge energy of 57 kW sec. This generator is of somewhat unusual design in that all the capacitors are contained in a central column of bakelised paper, and that it is of comparatively small size in relation to its output. The well-known Marx circuit is employed, and this has 12 stages charged to a maximum d.c. voltage of 200 kV, obtained from a mechanical rectifier. The generator is on rails and may be moved to four alternative operating positions. The impulse voltage wave is monitored by means of a resistance capacitance voltage divider and transient recorder, with facilities for visual examination and photographic recording of wave shape.

High voltage a.c. testing in the large test bay is carried out by the use of two 500-kVA 333-kV Ferranti transformers. One of these transformers is insulated from earth for 333 kV, and, by means of a cascade connection, the maximum output voltage can therefore be 666 kV. These transformers are also employed for power factor tests by the Schering-Bridge method, using a standard condenser of the compressed-gas type of 100 Pico-farads capacitance, suitable for use up to 500 kV. Voltage measurement is by means of a sphere gap, using spheres 1·5 m in diameter.

In the smaller bay of the laboratory there is an 800-kV Ferranti impulse generator, which has four 200-kV stages and a total surge energy of 22·4 kW sec. High-voltage a.c. testing is catered for by a 300-kVA 150-kV Ferranti transformer and a second unit rated at 100 kVA at 30 kV. A 50-cm sphere gap is used for voltage measurement, and a 100-kV 100 Pico-farad standard condenser is available for power factor testing.

Many other facilities are available in the laboratory, including suitable transformers for the heating of conductors of cable assemblies undergoing test, and equipment for the determination of the thermal resistivity of cable insulation.

# Abstracts from the World Technical Press

## Czechoslovak Progress in Hydro-Electric Developments

This comprehensive survey of the progress achieved during the last 15 years in construction techniques in Czechoslovakia is restricted to hydro-electric developments. During that relatively short period, the country put into commission no fewer than 37 new hydro-electric plants with a mean annual production of 2,500 million kWh, and the 21 reservoirs involved have a total storage capacity of 1,200 million m³. The economic importance of this advance in a country rather poor in utilisable water resources, expressed in terms of manpower applied to lignite mining, is perhaps best demonstrated by the fact that the few hundred millions of kWh produced in a year by the new Orlík plant alone represent the output of 600 men. The first instalment of this survey deals particularly with the production and placing of concrete, and includes the following paragraphs: preparation of aggregates, transport of cement, preparation of mixes and their transport, placing and compacting of concrete, quality of concrete, and winter concreting. The production, transport and placing of concrete has been thoroughly mechanised; compacting, however, is lagging behind, and there appears to be a lack of efficient vibrators at Czechoslovak dam-construction sites. In the second instalment, the article deals first at length with construction techniques aimed at speeding up the tempo of work, such as improved shuttering, use of prefabricated components, and new grouting methods. The application of television to work control is spreading; at Orlík, it has reached such a stage that the progress of injection is followed in the grout holes by means of television probes. Other paragraphs are devoted to foundation and rock work, as well as to earthworks. Many of the illustrations show the various stages of advance of the great Orlík project. The all-round progress achieved in Czechoslovakia is no mean performance, and compares favourably with results attained in countries where the initiation of hydro-electric developments is backed by many more years of practical experience and much wider possibilities of application. Great attention is paid to the training of specialised groups, so as to improve teamwork. Another interesting point, which is said to have paid fair dividends, is the care devoted by the organisations controlling hydro-electric projects to the welfare and general comfort of the workers, especially at sites fairly distant from inhabited places. (Ing. Alois Kraus, *Inženirske stavby*, Vol. 1960, No. 11, November 1960, p. 401. 8 pp, 15 ff.; No. 12, December 1960, p. 441, 9 pp., 20 ff.)

## Exponential Grading of Aggregates

This paper deals with a method of mass-concrete-mix design used to make concrete of maximum density at a minimum cost for the construction of the Whakamaru dam, a gravity structure with a volume of about one-third of a million cu yards, designed and built by the Ministry of Works, New Zealand. Although the head office of the Ministry of Works informs site staff of modern dam-concrete techniques and directs the work generally, the staff of the individual projects employs concrete-mix designs best suited to local conditions. The design method described was developed in 1954 in order to provide a satisfactory and simple step in the design of a concrete mix. Briefly defined, its purpose is to determine the exponent $x$ in the formula $P=(d/D)^x$ applied to the proportioning of coarse aggregates. In the instance of the Whakamaru dam it aimed primarily at finding a solution to the particular problem of making economic, dense concrete from lightweight aggregate of volcanic origin, and has been used with success on two more recent projects. Concretes of different water and cement contents, and containing the maximum size of aggregate given by the design method, were given field trials during which characteristics such as response to vibration and segregation were noted. The mixes proved workable and extremely economical, and placing proceeded satisfactorily. The measured loss of air after vibration was about 0·5% of the concrete volume, which resulted in a concrete *in-situ* density

**SNOWY MOUNTAINS HYDRO-ELECTRIC AUTHORITY (AUSTRALIA)**
**Four 110 000 BHP Francis turbines for the TUMUT 2 Power Station**

slightly greater than the calculated unit weight. The method may also be of value to concrete engineers who wish to design "first trial" mixes quickly. (W. M. Slater, *N.Z. Engineering*, Vol. 15, No. 7, July 15, 1960, p. 232, 9 pp., 6 ff., 7 tables.)

## Frequency, Governing and Other Problems

This is one of the papers read at a debating session held in Bern by the Swiss Association of Electricians, with special reference to water-turbine-driven alternators. We are reminded at the outset that automatic equipment ensuring the governing of distribution networks according to the frequency-output law contributes to the improvement of the value of the energy generated by those hydro-electric plants that utilise storage. The author then refers to the basic principle of such governing systems, stresses the advantages of modern equipment recently developed under the name of output-phase-energy governing, and gives a brief description of the governing system installed at the two plants of the Grande Dixence project, Fionnay and Nendaz. (R. Comtat, Ateliers Sécheron, Genève, *Bulletin de l'Association Suisse des Electriciens*, Vol. 51, No. 10, May 21, 1960, p. 515, 7 pp., 8 ff.)

## Barron River Extension Project

A description is given of the civil-engineering works of this North Queensland extension project for which tenders have recently been invited. The contract is to include the supply of all materials, and the execution of four major works. The existing low weir of mass concrete is to be reconstructed on the same alignment to a length of 550 ft, and its crest will be raised from about 12 ft to nearly 25 ft above the river bed. This new weir will serve the dual purpose of providing pondage for flow regulation and of diverting water into the tunnel intake. A reinforced-concrete intake structure, adjacent to the weir and forming its right abutment, will lead water from the pond into a horizontal tunnel. The intake structure will have four openings, each 10 ft wide, with entrances protected by heavy screens and sector-type sluice gates. The horizontal tunnel, which will be about 5,390 ft long and have a finished diameter of 9 ft 6 in, will be excavated almost entirely in sound, very hard rock at depths varying between 50 and 425 ft below natural surface. It will run from the intake to the inclined pressure tunnel, and have near its downstream end a concrete-lined surge shaft of the cylindrical type. This shaft will be 24 ft in diameter by about 135 ft deep, and will incorporate a restricted steel orifice concentric with the bore of the tunnel. A silt extractor will be constructed a short distance upstream of the surge shaft, and a small chamber housing an 8-ft 9-in butterfly valve will be sited at the transition point between the two tunnels. The pressure tunnel, which will be excavated at a depth below the general zone of weathering in the rock, will run from the valve chamber to a point about 115 ft upstream from the power station, whence it will continue generally horizontally to the two turbines. The actual length of the tunnel depends on the adopted location of the underground machine hall, but is not expected to exceed 1,350 ft between the upper and lower bends. The power station will be approximately 138 ft by 32 ft in plan and 65 ft high, and will house two 30-MW vertical-shaft generating sets each driven by a 40,000 h.p. Francis turbine. In addition to a sloping access tunnel, 18 ft wide by 15 ft high and about 360 ft long, there will be a second tunnel some 400 ft long and 6 ft 9 in wide by 10 ft high, which will leave the machine hall near roof level, and serve as a ventilation and cable gallery as well as an emergency exit. From this latter tunnel, a branch 8 ft wide by 10 ft high will lead to the tailgate chamber in which the draft tubes join. This gate chamber will also act as a tailrace surge tank. Discharge to the river is by means of a 12 ft wide tailrace tunnel, about 900 ft long, which is of the fully drowned type, and an open channel. An exploratory tunnel on the line of the permanent cable and ventilation gallery is being driven into the area in which the machine hall is to be excavated. A portion of the tailrace channel and a reinforced-concrete retaining wall on the river side of the working bench and switchyard, together with a culvert to divert the adjacent gully, will be constructed prior to the commencement of the contract. (*Australian Civil Engineer*, Vol. 1, No. 9, June 6, 1960, pp. 40–43, 1 f.)

## Comparing Kaplan and Dériaz Turbines

This is a reprint of the paper presented on the occasion of the Golden Jubilee of the Indian Institute of Science at Bangalore. Following a short historical survey of the development of the Dériaz turbine and of its applications, the author reviews the hydraulic and mechanical factors considered when comparing the two types of turbine, and then briefly discusses the results of the comparative tests carried out at the hydraulic laboratory of the English Electric Co. Ltd. in Rugby. The tests were effected on a turbine model which could be fitted either with an eight-blade Kaplan runner 519 mm in external diameter or a ten-blade Dériaz runner with an overall diameter of 508 mm. The scroll, gate-operating mechanism and draft-tube elbow were common to each runner so that they operated under identical conditions. The results given support the author's claim that, for heads exceeding 36 m, the mixed-flow Dériaz turbine shows marked advantages over the axial-flow Kaplan machine. The possibilities of application of the Dériaz type have not been fully explored yet, and the author claims that the superiority of the new type will be more pronounced in reversible pump-turbines operating in conjunction with pumped-storage plants. (P. Dériaz, *La Houille Blanche*, Vol. 15, No. 4, June, 1960, p. 331, 13 pp., 14 ff.)

## South Saskatchewan River Dam

Although it is primarily an irrigation project for the Prairie Farm Rehabilitation Administration, the South Saskatchewan River project will also include power facilities and provide flood-control benefits. The main dam, of rolled-earthfill construction, will be 210 ft high and three miles long, and thus it will become Canada's largest earthfill dam and one of the world's greatest structures of its kind. Five concrete-lined tunnels, each 20 ft in diameter and 4,000 ft long, will initially be employed to divert the river when final closure is made for second-stage construction, and will ultimately serve as power tunnels. A controlled concrete spillway, with an overall length of 17,000 ft and a capacity of 265,000 cusecs, will be sited about a mile from the main dam and will be connected to the reservoir by a canal 8,000 ft in length.

To control the flow of water from the main reservoir into the Qu'Appelle Valley, an auxiliary earth dam will be built at the divide between that valley and Aiktow Creek, a tributary of the Saskatchewan River. This control structure will be 90 ft high, 9,000 ft long and 700 ft wide at the base. In addition to the 500 miles of irrigation canals comprised in the project, there will be a 150-MW power plant. This article describes how construction work proceeded at the main dam without interruption during last winter, when 50-ton rollers operated in sub-zero temperatures with no undue trouble. Work is now under way on the upstream and central sections of the diversion tunnels, excavation of the spillway basin, embankment construction in the Coteau Creek area adjacent to the spillway, and on approximately 25 miles of highway relocation. (G. A. MacKenzie, *Engineering News Record*, Vol. 165, No. 5, August 4, 1960, pp. 34–36, 3 ff.)

## The Sufers Arch Dam

This article is another in the series published in the undermentioned journal on the various sections of the project designed by Motor-Columbus A.G., Baden, for the Hinterrhein development. This paper deals especially with the studies on which the design of the dam is based. The type selected as the most suitable was a constant-angle arch dam in which the traditional circular arch has been kept as the horizontal element of curvature. The main characteristics are as follows: the maximum height above the foundations is 58 m; the crest length is 125 m; the upstream crest radius is 63 m; the included angle of the crest is 105°; the minimum thickness is 3 m at the crest and 8 m at the base; the volume of excavation is 15,000 m³; the volume of concrete is 20,000 m³. Following a detailed description of the dam site, the authors review the procedures adopted for determining and reanalysing the design of the dam; these procedures are derived from the method of stress analysis generally adopted in connection with concrete dams, and are based on the theory of cantilevers. The adjustment of radial deflections is dealt with. The final paragraph is devoted to the effects of temperature loads. (Dipl. Ing. René Ribi and Dipl. Ing. Niklaus Schnitter, *Schweizerische Bauzeitung*, Vol. 78, No. 29, July 21, 1960, p. 479, 8 pp., 7 ff.)

## Repairing Turbine Runners

A welding specialist tells how his organisation applies steel inlays to turbine runners damaged by cavitation, without taking them out of the setting. A pattern is first made of the affected area and usually the irregular edges are squared up to a uniform outline. The metal is then gouged out to a depth of $\frac{1}{8}$ to $\frac{3}{16}$ in round the edges and a series of grooves of uniform depth, approximately $\frac{3}{4}$ in apart, is run through the outlined area. After checking the depth of the grooves the metal between them is cut away either by chiselling or arc-air torch. The latter process, of course, is much faster but overheating must be avoided or serious warping can occur. To cut the grooves first has been found the best way to ensure keeping the original contour of the blade. Welding is done in much the same sequence. A series of beads is run in a pattern $\frac{3}{4}$ in apart and, after the height has been checked, the space between is filled. If this procedure is not followed, there is a tendency for flat spots to occur. The welders must be artists, for stainless steel is not the easiest metal to grind. The author's organisation uses specially made wheels, plugs, and discs, with various grits, bonds, and degrees of hardness; the best tool is a 6- or 8-in, 5,000-r.p.m. grinder, 18 to 24 in long, for the rough work. For fine work and for the finished surface, disc (and offset) grinders are used. Welding rods are stored in sealed boxes, and the day's supply of rods is drawn from a hot box which is thermostatically controlled to 150°F. To give a quick check of the inlay depth, special magnetic pencils, designed so that they do not adhere if the inlaid metal is over $\frac{1}{8}$ in thick, are used. Francis-type wheels are the easiest to repair without warping, whereas Kaplan-type blades require very strict control of the sequence and amount of welding. (Martin Friedmann, Jr., *Power Engineering*, Barrington, Illinois, August, 1960, pp. 78/79, 4 ff.)

## Construction Work at Puntarikoski Rapids

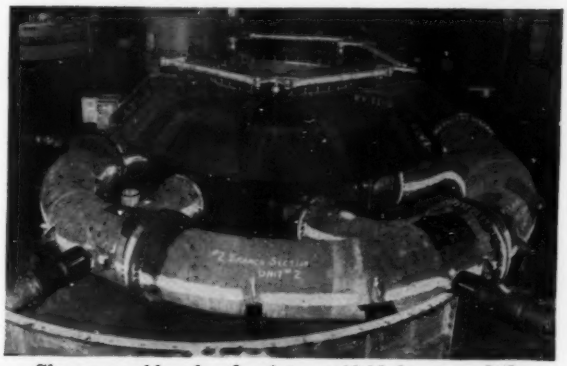
This article deals with some of the details of the construction work involved in the headrace and tailrace of this Finnish development, as well as in the timber-floating installations. An illustration shows the timber locks and the equipment for handling timber in 13-m³ bundles at the rate of 28 bundles per hour. The handling crane, which has a lifting capacity of 15 to 20 tons, has a luffing radius of 17 m. The location of the cofferdams is also well illustrated. The tailrace was excavated by means of a dragline fitted with a 3-m³ bucket, which removed about 750,000 m³ of material including 35,000 m³ of rock. (Veli Hakari, *Vesitalous* (Finnish Journal for Water Supply and Engineering), Vol. 1, No. 3, 1960, p. 22., 3 pp., 8 ff.)

## Planning Pumped-Storage Schemes

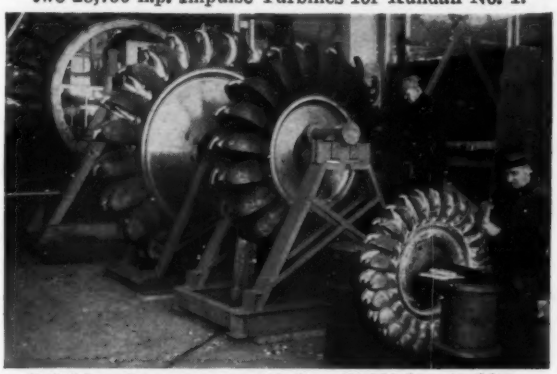
This article, an abridged version of the paper read at the 1960 World Power Conference in Madrid, discusses the factors intervening in the planning of pure pumped-storage schemes, i.e., schemes in which the upper reservoir is fed exclusively by pumping without any natural inflow of water. The advantage of this type of installation is that the designer has much more latitude with regards to location, and the plant site can be selected closer to the load centre of a supply system. The first part of the paper is devoted to the design of the civil-engineering works and their importance, and it reviews in separate paragraphs: ground and geological conditions, apportionment of costs, upper reservoir, the various types of impervious blankets (clay, earth-concrete, concrete, bitumen), natural and artificial lower reservoirs, intake structure, penstocks, pressure shafts and tunnels, and power house. The second part deals with the mechanical equipment: type and size of generating and pumping sets, turbines, pump-turbines, hydraulic torque converter, manifolds, automation, and discharge and efficiency measurements. In a final paragraph, the author discusses the operating problems arising out of various patterns of pumped-storage schemes. (Karlheinz Haager, Fritz Hartmann and Otto Uitting, *Die Wasser-Wirtschaft*, Vol. 50, No. 12, December 1960, p. 328, 6 pp., 9 ff.)

NOTE: The above issue also contains an interesting article on the TVA, its multipurpose development, and the changes it has brought about in the Tennessee landscape.

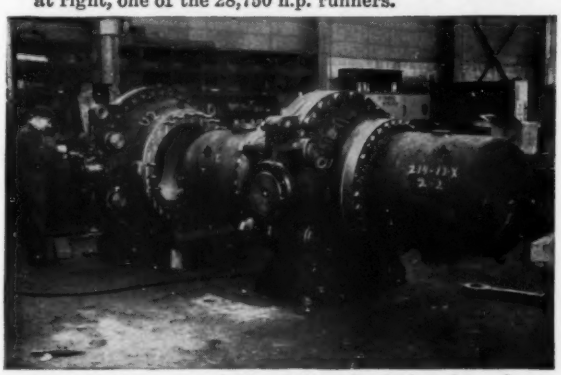
# SHIP TO: KUNDAH - INDIA



Shop assembly of a five-jet manifold for one of the two 28,750 h.p. Impulse Turbines for Kundah No. 1.



Polishing the runners—at left, a 50,000 h.p. turbine, at right, one of the 28,750 h.p. runners.



Shop-testing one of the 2'6" spherical valves for Kundah No. 2 at a pressure of 2,140 psi.

## "IT MAKES LIGHT WHERE THERE WAS DARK."

Rangaboyan said that. He is foreman of a crew pouring concrete for the Kundah Hydro-Electric Project in Madras.

It would probably not mean much to Rangaboyan if you told him that there are two Dominion Impulse Turbines at Kundah No. 1, developing 28,750 h.p. each under a head of 1,186 feet, and four turbines at Kundah No. 2 producing 50,000 h.p. each under 2,470 feet, and that Dominion Spherical Valves can shut off each turbine and hold back this enormous water pressure.

He might agree politely to your statement that the Kundah Development is one of the largest Colombo Plan Projects, and that its total cost will amount to $70,000,000.

And he wouldn't know what you were talking about when you told him that Kundah's total annual capacity of about 8 million KWH is enough to increase the present per capita consumption in Madras by 50%—from 36 KWH to just over 50 KWH.

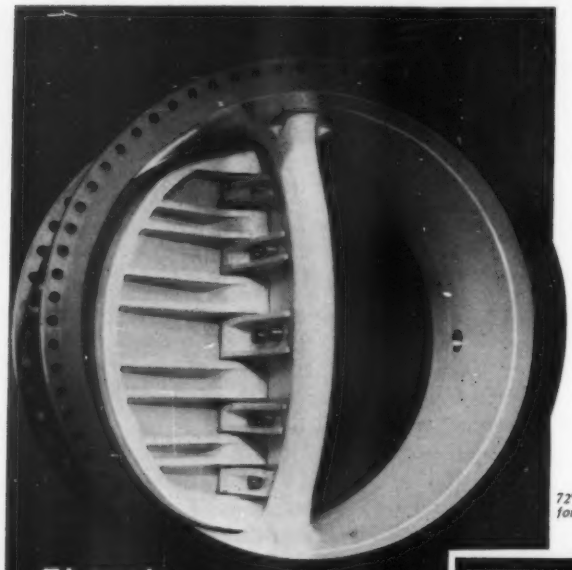
Rangaboyan, you see, cannot read or write. Yet he said it all with simple directness—"it makes light where there was dark".

Write for Bulletin 201-59—"Hydraulic Turbines"—to

**DOMINION ENGINEERING**
COMPANY LIMITED

Head Office: P. O. Box 220, Montreal, Canada • Branch Offices: Toronto—Vancouver

# *Butterfly Valves are not what they used to be*



*72" diameter tight closing Butterfly Valve for 730 ft. hd. operating pressure.*

The old orthodox design of butterfly valves with all their inherent weaknesses are now things of the past. A completely new and patented bridge bearing system is incorporated in Gordon Butterfly Valves enabling very high pressure drops to be easily and smoothly controlled.

These design principles together with a choice of tight sealing methods which completely eliminate any shaft or peripheral leakage greatly extend the range of applications, and today Gordon Butterfly Valves are being specified in a wide range of industries from iron and steel works to nuclear engineering and wind tunnel operations.

Available in sizes from 6" and upwards (standard designs include a 108" diameter valve), standard or purpose made, and in materials to suit almost any application, they could well play an important part in your organisation. *Full details supplied on request.*

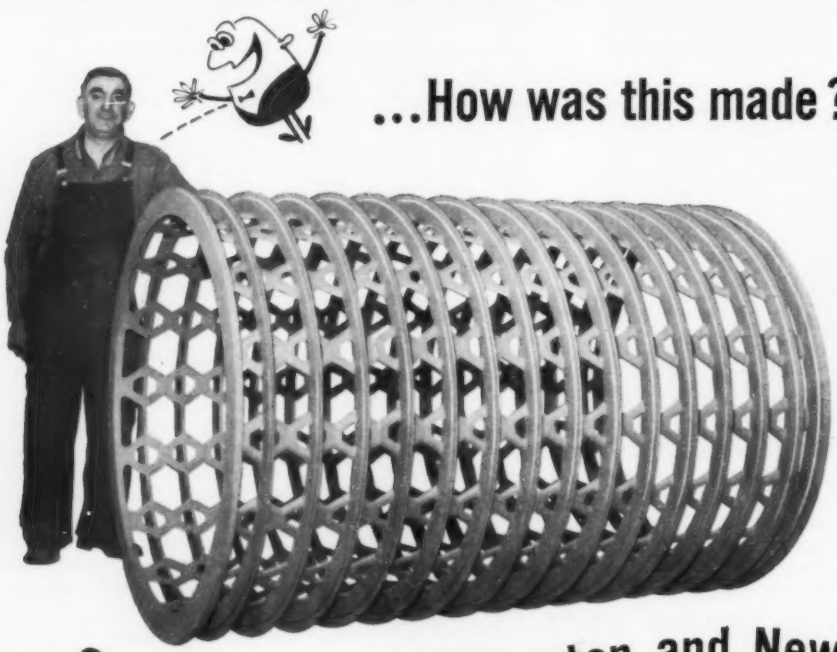
*A member of the Elliott Automation Group.* EA

There's hundreds of uses for **GORDON VALVES**

**JAMES GORDON VALVES LTD · AIRPORT WORKS · ROCHESTER · KENT**
*Telephone: Chatham 44400*

C/2

---



# ...How was this made?

## Castings from a few ounces to 20 tons

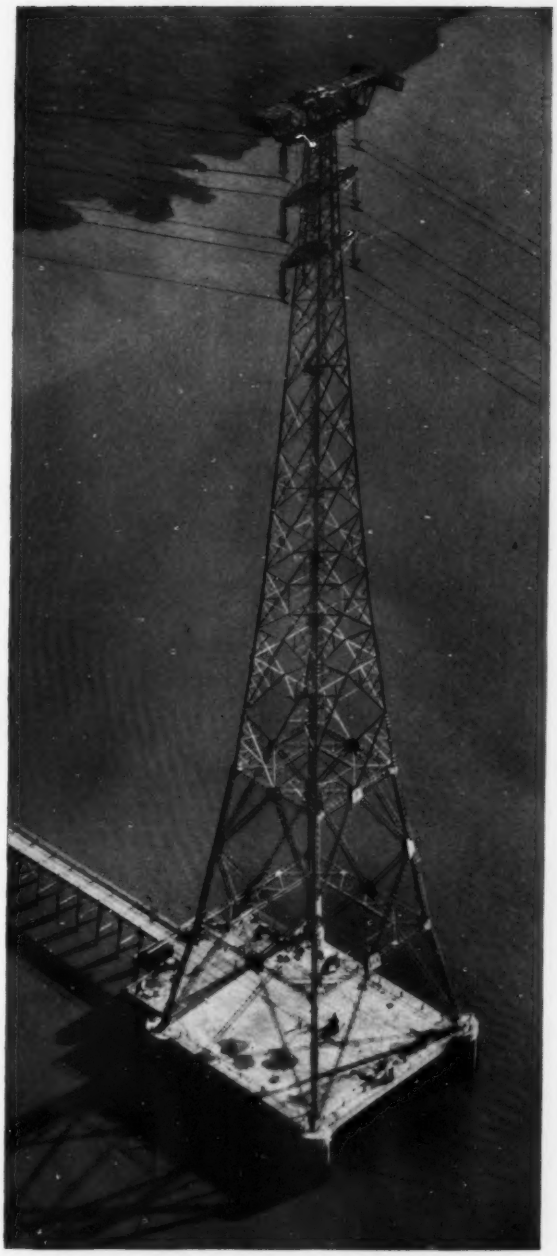
**NON-FERROUS CASTINGS**
**HIGH DUTY IRON CASTINGS**
**PRECISION MACHINED BUSHES & BEARINGS.**

This intricate hollow design casting in aluminium-bronze is only one of the many different specials regularly produced each week by the BIRSO foundries. Welded together from six separate sections to make a complete unit measuring 6 ft by 4 ft, the design is a patent of W. Knowles Trotman and used in the manufacture of paper and board throughout the world. We are specialists in the casting of specials — contact us today for full details of our facilities — and if you've a really difficult casting specification, send that too.

# Consult Birkett, Billington and Newton

**T. M. BIRKETT, BILLINGTON AND NEWTON LIMITED**
**HANLEY AND LONGPORT, STOKE-ON-TRENT, ENGLAND**
**Head Office: HANLEY, Phone: Stoke-on-Trent 22184/5/6/7** **LONGPORT, Phone: Newcastle, Staffs. 51433/4**

BIRSO TRADE MARK BN



RIVER SEVERN
CROSSING TOWERS
500-FT. HIGH

Main Contractors: J. L. Eve Construction Co. Ltd.
By courtesy of Central Electricity Generating Board

**Tees Side Bridge**
**& ENGINEERING WORKS LTD.,**
MIDDLESBROUGH. TELEPHONE: 45501-6
LONDON OFFICE: 56 VICTORIA STREET, S.W.1. TEL: ABBey 1613

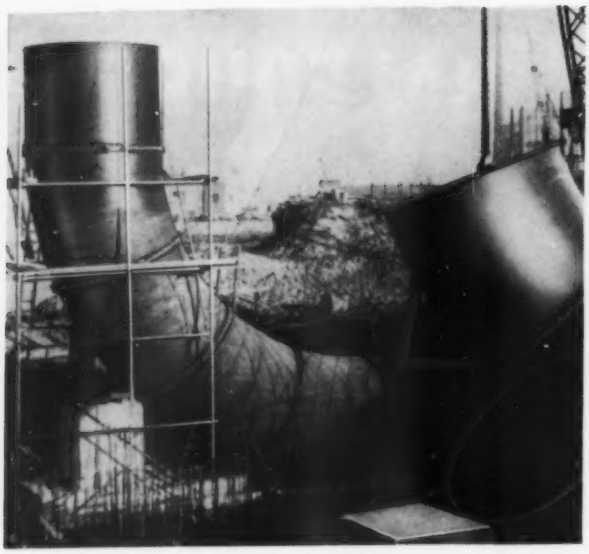
# BALFOUR BEATTY & CO. LIMITED

***CIVIL AND ELECTRICAL ENGINEERS AND CONTRACTORS***

**Comprehensive Engineering Service for projects in all parts of the world**

**Head Office: Bow Bells House, Bread Street (Cheapside), London, E.C.4.**

**Overseas**
**CANADA : EAST AFRICA : NIGERIA**
**MALAYA : PAKISTAN : IRAQ**



# FABRICATED PIPEWORK

Steel Piping, riveted or welded; straight lengths, bends and specials, from 10 in. diameter upwards. Standard or special joints supplied. Pipeline construction in any part of the world.

**MECHANS** LIMITED

SCOTSTOUN IRON WORKS, GLASGOW, W4.
Telephone: Scotstoun 2211

**THE RAILWAY GAZETTE**
A journal of Railway Management, Engineering, Operation and Railway News. *Weekly 2s. Annually £5 by post.*

**DIESEL RAILWAY TRACTION**
A monthly review of world-wide developments in diesel-engine design and diesel railway traction.
*Monthly 2s. 6d. Annually 35s. by post.*

**SHIPBUILDING AND SHIPPING RECORD**
A journal of Shipbuilding, Marine Engineering, Docks, Harbours, and Shipping. *Weekly 2s. Annually £5 by post.*

**NEW COMMONWEALTH**
Describes and illustrates significant developments in production, trade, transportation, and related spheres in all countries of the Commonwealth. *Monthly 2s. 6d. Annually £2 by post.*

**COLLIERY ENGINEERING**
A practical journal for Colliery Managers and Engineers, and manufacturers of Colliery Equipment.
*Monthly 2s. 6d. Annually £2 by post.*

**COKE AND GAS**
A technical journal dealing with the scientific and technical problems involved in the production of coke and gas in coke ovens and gasworks. *Monthly 2s. 6d. Annually 35s. by post.*

**THE INDUSTRIAL CHEMIST**
A journal devoted to the progress of applied Chemistry and Engineering. *Monthly 2s. 6d. Annually £2 by post.*

**WOOD**
A practical journal, authoritatively written, superbly illustrated, dealing with the growth, marketing and use of wood in all its forms. *Monthly 2s. 6d. Annually 35s. by post.*

**FOOD PROCESSING AND PACKAGING**
A journal devoted to the manufacture, packaging, and marketing of processed foodstuffs. *Monthly 2s. 6d. Annually £2 by post.*

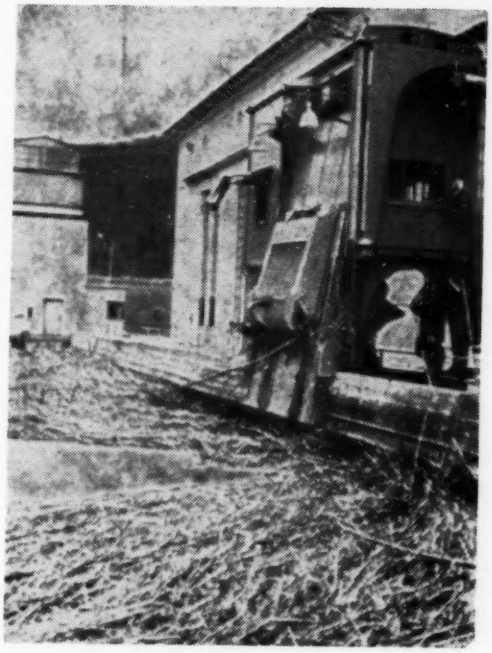
**WATER POWER**
A technical journal devoted to the study of all aspects of Hydro-Electric Development. *Monthly 2s. 6d. Annually £2 by post.*

**THE RAILWAY MAGAZINE**
A popular magazine containing illustrated articles on Railways and Locomotives. *Monthly 2s. 6d. Annually 35s. by post*

**MINE AND QUARRY ENGINEERING**
Articles of technical nature cover geology, modern methods of prospecting, the winning of ore and stone, the dressing of ore and minerals, and extraction metallurgy.
*Monthly 2s. 6d. Annually 35s. by post.*

**TOTHILL PRESS LIMITED**

**33, Tothill Street, Westminster, London, S.W.1**



***Racks and***

***Rack Cleaning Machines***

***for***

HYDRO-ELECTRIC POWER PLANTS

WATER PURIFICATION PLANTS

PUMPING STATIONS

●

**ENGINEERING WORKS**

# JONNERET S.A.

GENEVA (JUNCTION) SWITZERLAND

---

FASTER · SAFER · CHEAPER
"White" Aerial Ropeways carry a large variety of materials up to 300 tons per hour and are in daily service in many parts of the World. They have proved their great efficiency and saving of time in large-scale transportation programmes by Hydro-Electric schemes Collieries Quarries and Power Stations. Whatever the terrain, our 90 years specialist experience is at your service.
WHITES
of Widnes
Established 1869
R. WHITE & SONS (ENGINEERS) LTD.
G.P.O. BOX 2, WIDNES, LANCASHIRE
Telegrams: "RAILS, WIDNES." Telephone: 2425 (3 lines)

# INDEX TO ADVERTISEMENTS


**A**

Acciaieria E Tubificio Di Brescia ... — 
Allgemeine Elektricitäts-Gesellschaft ... — 
Alimark Verken A.B. ... — 
Allis-Chalmers Hydraulic Division ... 30 
Allmanna-Svenska Electriska Aktiebolaget ... 17 
Ansaldo San Giorgio, S.p.A. ... Inside Back Cover 
Associated Electrical Industries (Instrumentation Division) ... 16 
Associated Electrical Industries (Manchester) Ltd. — 
Associated Electrical Industries (Rugby) Ltd. Front Cover 
Associated Electrical Industries (Woolwich) Ltd. ... 16 
Ateliers de Constructions Electriques de Della ... — 
Atlas Copco, A.B. ... 26 & 27

**B**

Balfour, Beatty & Co. Ltd. ... 57 
Bell, Theodore & Co. Ltd. ... 7 
Birkett, T. M., Billington & Newton Ltd. ... 56 
Bochumer Verein ... — 
Bouchayer & Viallet ... — 
Boving & Co. Ltd. ... 5 
Boyles Bros. Drilling Co. Ltd. ... 14 
British Ropeway Engineering Co. Ltd. ... — 
Brown, Boveri & Co. Ltd. ... 15 
Bruce, Peebles & Co. Ltd. ... — 
Bucyrus-Erie Co. Ltd. ... — 
Buss, A.G. ... — 
Butters Bros. & Co. Ltd ... —

**C**

Canadian General Electric Co. Ltd. ... — 
Canadian Vickers Ltd. ... 4 
Canadian Wood Pipe & Tanks Ltd. ... 20 
Ceretti & Tanfani Ropeway Co. Ltd. ... — 
Charmilles Engineering Works Ltd. ... 54 
Cockburns Ltd. ... 28 
Compagnie Industrielle de Travaux ... — 
Consolidated Pneumatic Tool Co. Ltd. ... —

**D**

de Roll, Louis, Ironworks Ltd. ... 3 
Dominion Engineering Co. Ltd. ... 55 
Doulton Industrial Porcelains Ltd. ... 41 
Drees & Co., G.m.b.H. ... 23

**E**

Eimco (Great Britain) Ltd. ... 52 
ELIN, A.G. ... — 
Elliott Bros. ... — 
English Electric Co. Ltd. ... Outside Back Cover 
English Steel Forge & Engineering Corporation Ltd. 42 
Escher Wyss Ltd. ... —

**F**

Ferranti Ltd. ... — 
Ferrum Montage ... — 
Fischer, Ltd., George ... —

**G**

Galileo Officine di Battaglia Terme ... 31 
General Electric Co. Ltd. ... — 
Gilbert Gilkes & Gordon Ltd. ... — 
Giovanola Freres, S.A. ... — 
Glenfield & Kennedy Ltd. ... 36 
Gordon Valves, J., Ltd. ... 56

**H**

Harland Engineering Co. Ltd., The ... — 
Hartley (Stoke-on-Trent) Ltd. ... — 
Henderson, John M. & Co. Ltd. ... — 
Hitachi Ltd. ... 6 & 43 
Huhn, G. ... 59 
Hydraulics & Pneumatics Ltd. ... — 
Hydraulic Service & Equipment Co. Ltd. ... —

**I**

Impresit Girola Lodigiani S.P.A ... 39 
INGFA ... — 
International Engineering Co. Inc. ... — 
International General Electric Co. ... —

**J**

Jonneret, S.A. Ateliers de Construction ... 59

**K**

Karlstads Mekaniska Werkstad, Akt. ... 9 
Krupp, Fried. Maschinen- und Stahlbau ... 53 
Kuljian Corporation, The ... 24 
Kvaerner Brug A.S. ... 47

**L**

Leffel, James & Company, The ... 40 
Lepper Transformatorenwerk August ... — 
Le Materiel Electrique, S-W ... — 
Limi Torque ... —

**M**

Magrini, S.p.A. ... — 
Maschinenfabrik Augsburg-Nürnberg, A.G. ... 13 
Maschinenfabrik B. Maier ... — 
Mechans Ltd. ... 58 
Micanite & Insulators Co. Ltd., The ... 45 
Michell Bearings Ltd. ... — 
Mitchell Construction Co., The ... 25 
Mitsubishi Electric Manufacturing Co. ... 29

**N**

Neyrpic ... 40 
Nippon Gaishi Kaisha Ltd. ... 38 
Nuttall, E., Son & Co. (London) Ltd. ... — 
Nydqvist & Holm, A/B ... 51

**O**

Oerlikon Engineering Company ... 44 
Ossberger Turbinenfabrik ... —

**P**

Pirelli-General Cable Works Ltd. ... —

**R**

Ransomes & Rapier Ltd. ... 18 
Reyrolle, A. & Co. Ltd. ... Inside Front Cover 
Rheinstahl Union ... — 
Riva Costruzioni Meccaniche ... 19 
Rosenthal Isolatoren, G.m.b.H. ... 58 
Ruston Bucyrus Ltd. ... —

**S**

S.A. Ateliers De Secheron ... — 
Sakai Iron Works Co. Ltd. ... 34 
Salvi, A. & Co. ... — 
Salzgitter Maschinen Aktiengesellschaft ... — 
Savoisienne ... — 
Scarpa & Magnano ... — 
Siemens-Schuckertwerke, A.G. ... 48 
Smith, Fredk. & Co. ... — 
Soc. p. Az. Cementi Armati Ing. Mantelli ... — 
Societa Nazionale Delle Officine Di Savigliano ... 37 
Societe des Forges et Ateliers Du Creusot ... — 
South Durham Steel & Iron Co Ltd. ... — 
Steatite & Porcelain Products Ltd. ... 46 
Sulzer Bros. (London) Ltd. ... 50 
Svenska Metallverken, A/B ... —

**T**

Tampella OY ... — 
Technoexport ... 21 
Tees Side Bridge & Engineering Works Ltd. ... 57 
Terni Per L'Industria E L'Elettricita ... — 
Tokyo Shibaura Electric Co. Ltd. ... 12 
Torno, Giuseppe & Co. ... — 
Tosi, Franco, S.p.A. ... —

**V**

Vereinigte Osterreichische Eisen- und Stahlwerke ... — 
Victor Products Ltd. ... 22 
Vevey Engineering Works Ltd. ... 35 
Voith, J. M., G.m.b.H. ... 32

**W**

Waagner Biro, A.G. ... 33 
White, R. & Sons (Engineers) Ltd. ... 59 
Wood, Hugh & Co. Ltd. ... 8

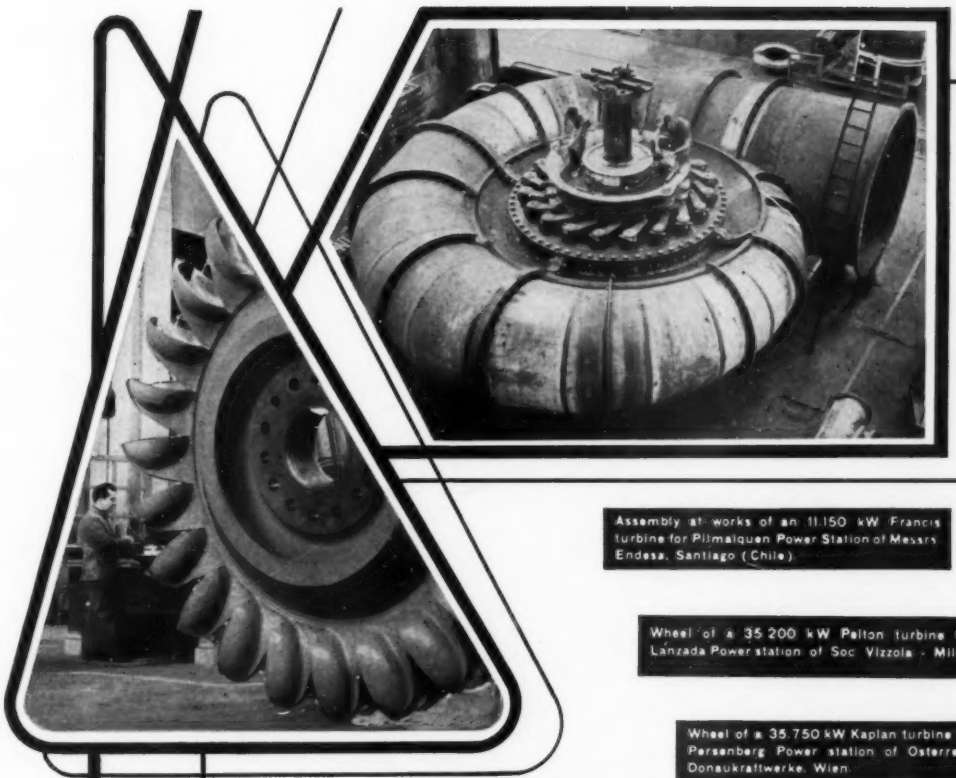
**Y**

Yorkshire Electric Transformer Co. Ltd. ... —



LONDON: Published by TOTHILL PRESS LIMITED, Proprietors of WATER POWER, at 33 Tothill Street, Westminster, S.W.1 and Printed by W. & H. SMITH, LTD., Evesham, Worcestershire. *April, 1961*

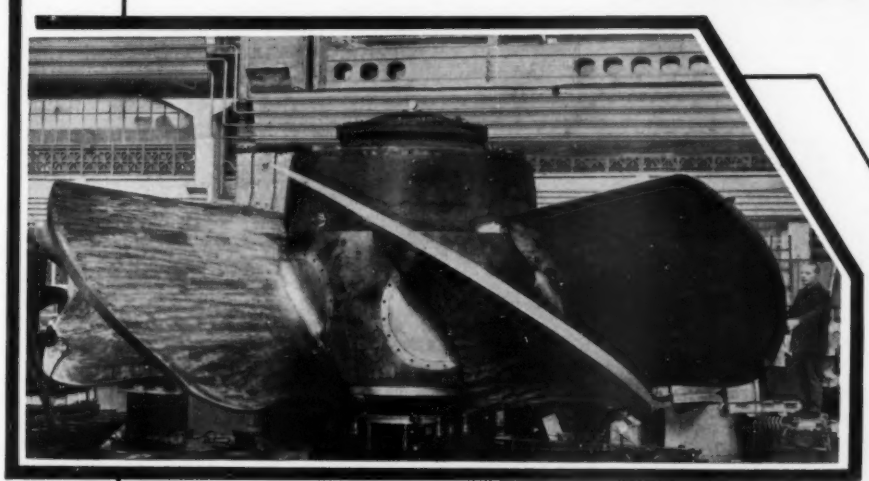
# Complete hydro-electric plants



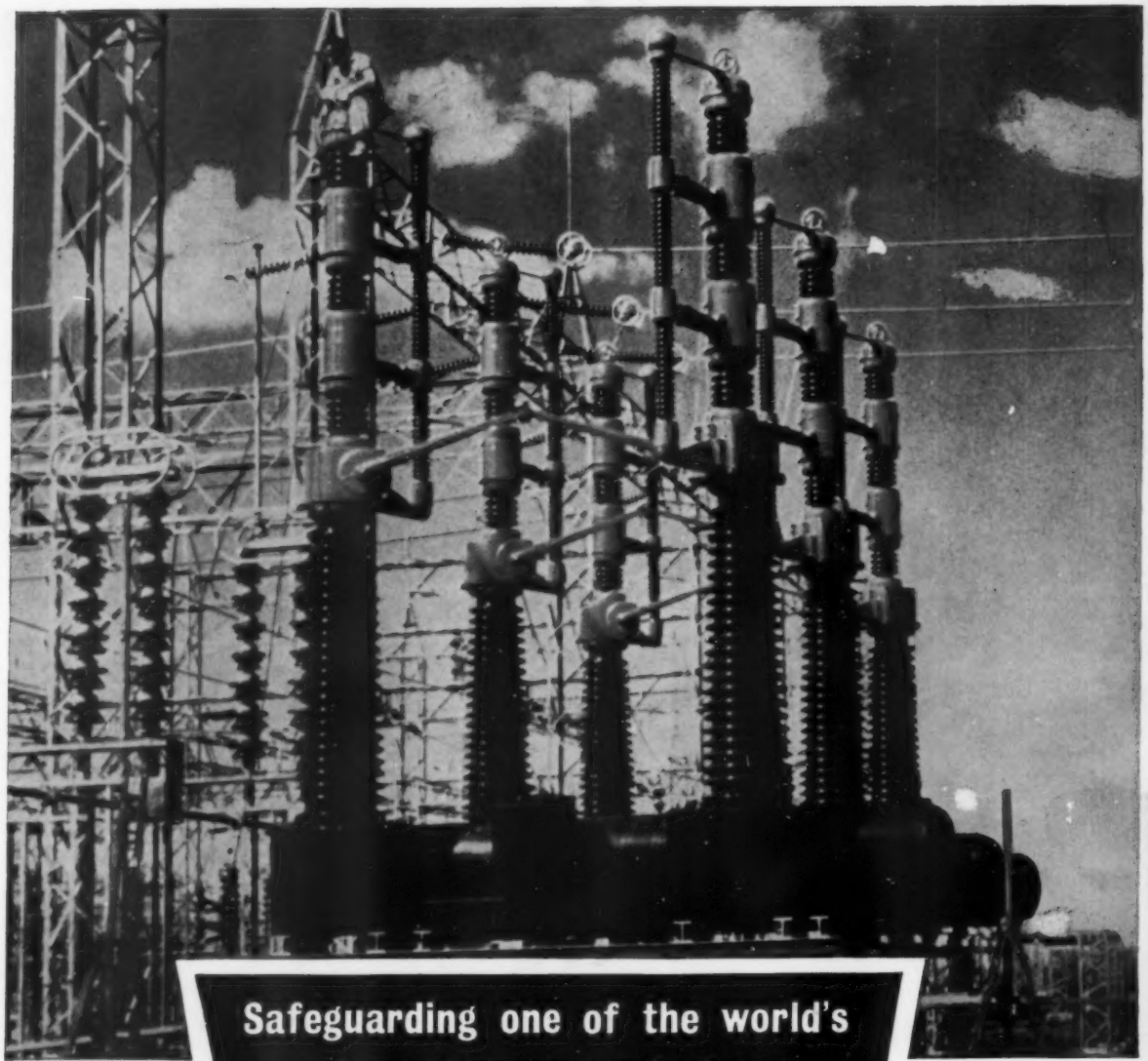
Assembly at works of an 11.150 kW Francis turbine for Pilmaiquen Power Station of Messrs Endesa, Santiago (Chile).

Wheel of a 35.200 kW Pelton turbine for Lanzada Power station of Soc. Vizzola - Milan.

Wheel of a 35.750 kW Kaplan turbine for Ybbs Persenberg Power station of Osterreichische Donaukraftwerke, Wien.



ANSALDO-SAN GIORGIO
GENOVA



## Safeguarding one of the world's largest power projects

The 'ENGLISH ELECTRIC' 330kV 10,000 MVA air-blast circuit-breaker at Hydro Quebec's Bout de L'Ile Terminal Station, which stands at the Montreal end of a 400 miles long 300 kV transmission line from Bersimis Generating Station, one of the world's largest hydro-electric projects. From the terminal station, power is transformed down to 120 kV for distribution throughout the Montreal area. Circuit-breakers of this type are designed for system voltages ranging from 220 kV to 345 kV.

*Send for publication SG/250*

# 'ENGLISH ELECTRIC'

## switchgear

THE ENGLISH ELECTRIC COMPANY LIMITED, ENGLISH ELECTRIC HOUSE, STRAND, LONDON, W.C.2

*Switchgear Department, Stafford*

WORKS: STAFFORD · PRESTON · RUGBY · BRADFORD · LIVERPOOL · ACCRINGTON

SGS 27A